



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>

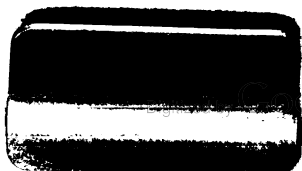
New

LIBRARY
OF THE
UNIVERSITY OF CALIFORNIA.

GIFT OF

H.B. LYNCH

Class



REPORT
OF THE
NAVAL ADVISORY BOARD
ON THE
MILD STEEL

**USED IN THE CONSTRUCTION OF THE HULL, BOILERS,
AND MACHINERY**

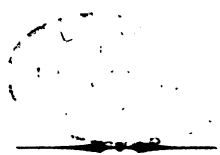
OF THE
DOLPHIN, ATLANTA, BOSTON, AND CHICAGO,

**FOUR STEEL VESSELS CONSTRUCTED UNDER THE ACTS
OF AUGUST 5, 1882, AND MARCH 3, 1883.**

PREPARED BY

ASSISTANT NAVAL CONSTRUCTOR R. GATEWOOD, U. S. N.,

FROM THE RECORDS OF THE BOARD.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1886.

11590 M S

VM162
46

LETTER OF TRANSMITTAL.

NAVAL ADVISORY BOARD,
NAVY DEPARTMENT,
Washington City, July 27, 1885.

SIR: The Board respectfully forwards herewith its report on mild steel supplied for the construction of the Chicago, Boston, Atlanta, and Dolphin.

This report has been prepared in accordance with the synopsis presented with our letter to the Department of November 17, 1884, by Assistant Naval Constructor R. Gatewood, U. S. Navy, from the data contained in records of the Board.

Very respectfully,

E. SIMPSON,
*Rear-Admiral U. S. N.,
President of the Board.*

Hon. W. C. WHITNEY,
Secretary of the Navy.

INTRODUCTION.

THE INCREASING USE OF MILD STEEL IN THE UNITED STATES PRIOR TO ITS ADOPTION AS THE MATERIAL OF CONSTRUCTION FOR THE FOUR VESSELS APPROPRIATED FOR MARCH 3, 1883.

Mild Steel for Locomotive Boilers.—The advantages to be gained by the use for the fire-boxes of locomotives of a material sufficiently homogeneous to stand the heat of a coal fire with steam blast without the development of blisters, with consequent uncertain and generally short life, as with the iron plates then used, led the authorities of the Pennsylvania Railroad to construct in July, 1861, in its shops at Altoona, Pa., a fire-box of English (crucible) steel. Owing probably to improper manipulation, but, possibly, also to bad quality as well as too high carburization of the steel used, the first attempt was not successful, one of the plates, accidentally let fall after flanging, breaking in the most brittle fashion like glass. In 1865 a second fire-box was made, this time of American crucible steel, supplied by Hussey, Wells & Co. (now Hussey, Howe & Co.), of Pittsburgh, Pa., and was so successful in use that in the next year eighteen steel fire-boxes were constructed, seven of English steel and eleven of the above American steel; while, in June of the same year, 1866, an entire boiler was built of American metal. In 1867 eighteen fire-boxes were made of the same material.

From 1868 dates the decided use of steel for boiler construction by the Pennsylvania Railroad; in that year twenty-seven boilers of steel throughout, besides fifteen steel fire-boxes for iron boilers, being constructed. In 1869 thirty-seven steel boilers were constructed, and thereafter the number of iron boilers constructed diminished rapidly, the last one—a stationary boiler—being built in July, 1873. After 1868 all iron fire-boxes were replaced by steel as they came in for repairs, while improvement in quality of material and in workmanship is evident in the long life of these fire-boxes, from ten to even fifteen years, though not in such continued and severe service as is now common.*

All this success had been obtained with crucible steel of high cost, so that other railroads were naturally slow to undertake the change from iron to steel, although experimental boilers of steel from this time on commenced to appear on various roads. The Bessemer process was introduced into the United States in 1865, but soft steel so manufactured has not been used in locomotive-boiler construction to any extent. The open-hearth process, introduced in 1868, soon became the chief, and is

* The average life of a steel boiler on this road is now reckoned at thirteen years while that of a fire-box is only six years, the longer fire-boxes, 113 by 36 inches, having the shortest life.

now almost the only, source of supply, steel of this manufacture practically entirely replacing crucible steel after 1875.

The use of steel for boilers on the Pennsylvania Railroad was not without incidental failure both under construction and in service, though the care of steel boilers in use seems to have been the subject of considerable attention and helps to account for their special immunity from accident. Up to 1873 the steel was generally taken on the maker's guaranty, but from that year the testing of boiler steel became part of the regular routine work, and at present every sheet of boiler, fire-box, or tank steel used in the shops of the railroad, or in outside construction for them, is tested in the testing department of the road at Altoona, Pa. As the pioneer road in the use of steel in boiler construction, their specifications and method of test have been closely imitated by other prominent roads, and most of the high-grade mild steel made subject to test at the time of the adoption of this material for the construction of naval vessels was expected to fill these or similar specifications. Certainly not less than 7,500 tons of steel had been used in locomotive-boiler construction, of which probably 6,000 tons had been made to specifications and subject to test. The specifications and method of test in use are accordingly of interest as being those with which the steel manufacturers expressed familiarity and as being also probably the most rigid up to that time exacted.

SPECIFICATIONS FOR BOILER AND FIRE-BOX STEEL FOR THE PENNSYLVANIA RAILROAD.

(1) A careful examination will be made of every sheet, and none will be accepted that show mechanical defects.

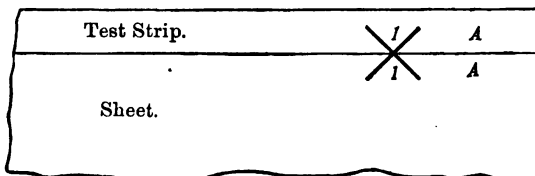
(2) A test strip taken from each sheet lengthwise of the sheet, and without annealing, should have a tensile strength of 55,000 pounds per square inch, and an elongation of 30 per cent. in a section originally 2 inches long.

(3) Sheets will not be accepted if the tensile strength is less than 50,000 pounds or greater than 65,000 pounds per square inch, or if the elongation falls below 25 per cent.

(4) Should any sheets develop defects in working, they will be rejected.

(5) Manufacturers must send one test strip for each sheet (this strip must accompany the sheet in every case), both sheet and strip being properly stamped with the marks designated by this company, and also lettered with white lead to facilitate matching.

The method of test is as follows: Each steel manufacturer is furnished with a so-called "shear-mark," which, together with a letter indicating the position of the sheet in the boiler, must be stamped upon each sheet. In removing the test piece, the plate is sheared through the "shear mark" thus, so that, when received at the works, the test



strips may be matched to the corresponding sheets. The piece is then shaped for test as in Fig. 1, in which it will be noticed that the 2-inch measured length for elongation includes $\frac{1}{4}$ -inch fillets at each end, and

that the proportion of the test piece is subject to important variation between the extremes of thickness of $\frac{1}{4}$ and $\frac{1}{2}$ inch.

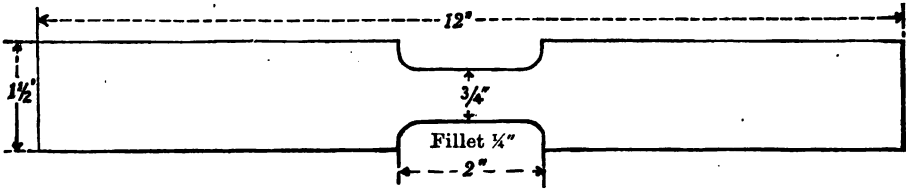


Fig 1.

The pieces are broken by continuous pull in a 100,000-pound Riehle hydraulic machine similar in all respects to that shown in Fig. 4, p. 403.

Similar specifications and methods of tests, with occasional slight individual modifications, are in use in most of our railroads, and in the large locomotive works for steel not specified for by the purchaser. A commendable tendency appears, however, towards the use of longer test pieces, as in the Chicago, Burlington, and Quincy Railroad, whose specifications are as follows:

A test strip lengthwise of the sheet, and without annealing, should have a tensile strength of 55,000 pounds per square inch and an elongation of 28 per cent. in a section originally 4 inches long. Sheets showing less than 50,000 pounds, or more than 60,000 pounds, or an elongation under 25 per cent., will be rejected. Samples to stand bending or hammering down, either hot or cold, after being chilled from a cherry red heat, without a flaw or crack.

Mild Steel for Stationary Boilers.—Information is not readily accessible as to the history or extent of the use of steel for stationary boilers, though thousands of tons have been so used, especially of late years. As to the degree of success obtained, Prof. R. H. Thurston mentions* that the manufacturing house of Kendall & Roberts, Cambridgeport, Mass., report that of several thousand boilers built of steel, they have never had one to fail or give any trouble. It is very likely that the supply of steel for this purpose is mainly under guaranty of the manufacturers.

Mild Steel for Naval Boilers.—The conditions under which this material was adopted and has been used by the Bureau of Steam Engineering, Navy Department, for the construction of naval boilers appear to have been as follows:

As early as April, 1875, samples of mild steel submitted by the well-known Otis Iron and Steel Company were tested at the Washington navy-yard, the tests being reported "very severe and in every way satisfactory." It would appear that up to this time requirements for tensile strength had not been exacted for boiler iron, but in 1877 efforts were made, by correspondence and public advertisement, to obtain for new boilers of the Nipsic a higher grade of iron than had hitherto been used, the specifications demanding "the very best quality of American flange iron, to stand a test of not less than 55,000 pounds to the square inch"—presumably in the grooved test piece then in general use—but without success. It was stated, however, that all the conditions could be met by using mild steel, and the Otis Iron and Steel Company again submitted samples of this material for test at the Washington navy-yard, the report on which (January, 1878) contains the opinion that "the advantages of this material for purposes under cognizance of the Bureau of Steam Engineering would be facility of working, security

* Trans. Am. Inst. Mech. Engrs., Vol. IV., 1883, p. 436.

against blisters in crown sheets of boilers, great tensile strength and consequent reduction in weight of boilers, and a longer life of boilers, on account of the corrosive action being less upon this material than upon ordinary iron." Shortly after (March, 1878), at the request of the authorities of the Fish Commission, mild steel was ordered as the material for new boilers for the Fish Commission steamer Lookout, built by agreement at the Washington navy-yard.

Meanwhile efforts were continued to obtain the higher grade of iron demanded for the Nipsic's boilers, and after the failure of numerous brands under test, samples of the well-known "Sligo" brand passed the tests. But the plates of this brand as supplied failed to meet the tests, and in view of the perfect working of the mild steel for the Lookout's boilers under construction, the agent was allowed to fill the contract with similar material.

Once in use, the material gave such satisfaction that no other has since been used. But before finally adopting it for general use, samples of various manufactures were sent to all the navy-yards for test in comparison with one another and with representative brands of iron, the reports being invariably favorable to the new material after due consideration of all qualities, including the higher cost of the steel.

Table I. gives the chief items of information for the steel used for this Bureau up to January 1, 1884, from which it is seen that mild steel for 111 boilers, requiring 3,411,780 pounds—1,523 gross tons—had been supplied.

TABLE I.—Mild steel supplied to the order of the Bureau of Steam Engineering for construction of main steam boilers (excluding auxiliary and cutter boilers) up to January 1, 1884.

Date of order.	Vessel.	Number of boilers.	Weight of steel delivered.	Navy-yard.
			<i>Pounds.</i>	
1878.				
Nov. 1	Nipsic	*6	129,961	Washington.
1879.				
July 3	Mohican	†8	156,989	Mare Island.
July 11	Iroquois	*6	154,638	Do.
Oct. 17	Despatch	*2	75,704	Washington.
1880.				
May 6	Ranger	*4	69,308	Mare Island.
May 10	Tallapoosa	*2	173,241	Washington.
June 30	Alert	*4	82,319	Mare Island.
June 30	Enterprise	*6	150,560	Washington.
June 30	Essex	‡6	164,607	New York.
June 30	Tuscarora	§6	77,452	Mare Island.
Sept. 16	Snowdrop	*1	35,658	Norfolk.
Oct. 26	Fortune	‡2	65,423	Washington.
Oct. 26	Pinta	*2	84,335	Do.
Dec. 18	Ticonderoga	§4	181,429	Do.
1881.				
May 9	Monongahela	‡4	189,511	Mare Island.
May 11	Ossipee	*4	181,324	Washington.
May 11	Rescue	*1	40,852	Do.
June 28	Marion	*8	176,761	Do.
Aug. 1	Pilgrim	*1	45,569	League Island.
Oct. 31	New York	‡6	299,141	Washington.
1882.				
June 28	Adams	‡6	130,035	Mare Island.
June 28	Alliance	‡6	129,252	Norfolk.
June 28	Benicia	§4	203,634	Mare Island.
June 28	Powhatan	§4	228,641	New York.
June 28	Vandalia	‡8	175,468	Norfolk.
Total		111	3,411,780	

*Completed and in service.

†Completed, but not in service.

‡Partially completed.

§ Not yet commenced.

¶ Partially completed for Monocacy.

This steel was first required to have a tensile strength of about 60,000 pounds to the square inch,* and to stand the severest flanging tests. In June, 1882, the requirements were "to stand the severest flanging tests, and have a tensile strength between 57,000 and 60,000 pounds to the square inch." In December, 1882, practically the same specifications were issued as subsequently adopted by this Board, viz: "To be of uniform thickness and smooth surface, to stand the severest flanging tests, and have a tensile strength between 57,000 and 60,000 pounds to the square inch, with a ductility in 8 inches of not less than 25 per centum."

Mild Steel for Bridges.—In the construction of the great Saint Louis bridge across the Mississippi River, in 1869, nearly 3,000 tons of steel were used, all crucible, and much of that description of crucible steel in which chromium, instead of carbon, is the chief hardening element. This steel is remarkable for its toughness, even in the harder qualities, but its cost is high. Its use at the time was considered a bold piece of engineering, and the experiment was not repeated.

The progressive use of mild steel for bridge building dates from 1879, when Bessemer plates and shapes were adopted for the roadway girders and the approaches of the East River suspension bridge. Thence, successively, railroad bridges in increasing number have been constructed of steel, as given in the accompanying Table II. Of course, the use of steel as wire is not here referred to, but only as worked in ordinary structural shapes. Open-hearth steel has been the preferred material, especially for tension members, a slightly harder grade being used than in ship construction, the general specifications being 70,000 to 75,000 pounds tensile strength, with 20 per cent. elongation of a $\frac{3}{4}$ -inch round in 8 inches. For compression members and pins, 80,000-pound steel, with correspondingly less elongation, is required. As illustrating the quality of material in use, extracts are given in the appendix (p. 577 *et seq.*) from the specifications for a railroad bridge recently constructed. Bridge specifications are not, however, generally so confining as to each individual quality of the material.

TABLE II.—*Steel Bridges in the United States.*

Date.	Bridges.	Steel manufacturer.	Weight of steel.	Description of steel.
			<i>Tons.</i>	
1869.	Saint Louis Bridge	Butcher	2,900	Carbon and chrome.
1870-'83	East River Bridge	Cambria Iron Company	6,300	Bessemer.
1880.	Plattsmouth Bridge .....	.....	497	Siemens-Martin.
1881-'82.	Bismarck Bridge	Spang Steel and Iron Company .....	.....	.....
1883.	Blair Bridge	Cambria Iron Company	432	Open-hearth.
1883.	Willamette Bridge	Spang Steel and Iron Company	600	Do.
1888.	Niagara (new R. R.) Bridge	do	250	Do.
1888.	Point Pleasant Bridge	{ do .....	.....	{ Do.
		{ Cambria Iron Company	100	{ Do.
1884.	Henderson Bridge	do	800	Do.
1884.	Port Deposit Bridge	Carnegie Brothers	5-6,000	Bessemer.

Mild Steel for Ship-Building.—The use of steel for ship-building was by no means so well advanced as in the other leading branches of iron construction. Only one establishment, the Pusey & Jones Company, of Wilmington, Del., appears to have given the subject practical attention, and they had constructed but five little river-steamers and six lighters with steel plating, most of which was imported. Neverthe-

*Presumably on a test piece 5 or 6 inches long, as these lengths were used by Boards reporting on the material.

less, they were in a position to express before the Congressional committee a decided opinion as to the reliability of steel hulls in collision and grounding, Mr. William Gibbons, president of the company, describing the behavior of one of these little vessels thus:*

"My company have built a number of steel vessels, several of which have been intended for the navigation of the river Magdalena, in the United States of Colombia. Parts of that river are rapid and full of rocks and snags, and the vessels were built of these sheets of steel, much thinner than we have ever used for iron vessels, and they have been thumped and banged against rocks and stones until one of those boats is all dinged, just as if you had taken a leather bag and kicked it about, yet there has been no sort of fracture."

It is seen from Table III., believed to be a complete account of steel ship-building in the United States up to the date of writing, that the four vessels for the Navy were the first to be commenced of steel throughout, although smaller vessels have been completed before them. Other vessels are under construction, and the list will be materially increased by the end of 1885.

* "Reconstruction of the Navy," H. R. Report No. 653, 47th Congress, 1st session, p. 122.

TABLE III.—Steel Ship Building in the United States.

Name of vessel.	Wholly or partially of steel.	Dimensions.			Displacement.		Type.	Owner.	Commenced.	Finished.	Description of steel used.	Tensile strength.	Ductility in 8 inches.
		Length.	Beam.	Depth.	Light.	Load.							
		<i>Ft. Ins.</i>	<i>Ft. Ins.</i>	<i>Ft. Ins.</i>	<i>Tons.</i>	<i>Tons.</i>						<i>Lbs. per sq. in.</i>	<i>Per ct.</i>
Tollmas*	Plating only.	100 0	24 0	4 0	100	100	Side-wheel steamer.	F. J. Cisneros, Barranquilla, U. S. Colombia.	1879	1879	Purchased through agents.	55,000 to 60,000	16
Santa Marta*	do.	60 0	15 0	3 0	26	26	Stern paddle-wheel steamer.	do.	1879	1879			
Ronce de No- viembre.*	do.	120 0	24 0	4 0	120	120	do.	Government of U. S. of Colombia.	1879	1879			
Emilia Du- ran.*	do.	40 0	10 0	3 0	13	13	do.	do.	1879	1880	Unknown.	55,000 to 60,000	16
2*	do.	55 0	25 0	3 6	40	40	Lighters	do.	1881	1882			
4*	do.	50 0	18 0	3 0	25	25	do.	do.	1881	1882			
(*)	do.	36 0	7 6	3 6	7	7	Propeller	Junta de la Canalizacion del Rio Magdalena.	1883	1883	Domestic open-hearth.	65,000	16
Olympian*	do.	260 0	40 0	14 3	1,246	1,400	Side-wheel bay steamer.	Oregon Railway & Navigation Co.	1883	1883			
Apure*	do.	150 0	30 0	6 0	230	230	Stern paddle-wheel steamer.	General Steamship Co., Trinidad, W. I.	1883	1884	Purchased through agents.	55,000 to 60,000	Over 28
Libertad*	do.	75 0	17 0	4 0	40	40	do.	do.	1883	1884			
Dolphin†	Wholly.	240 0	32 0	19 9	1,500	1,500	Dispatch boat.	U. S. Navy	1883	1885			
Atlanta†	do.	270 0	42 0	26 3	3,000	3,000	Protected cruiser	do.	1883	1883	do.	do.	Do.
Boston†	do.	270 0	42 0	26 3	3,000	3,000	do.	do.	1883	1883	do.	do.	Do.
Chicago†	do.	315 0	48 2	34 10	4,500	4,500	do.	do.	1883	1884	do.	do.	Do.
Norwalk†	do.	221 0	30 0	20 0	850	1,150	Propeller yacht.	William Astor, New York.	1883	1884	do.	65,000	16
Electra†	do.	163 0	23 0	14 3	350	450	do.	E. T. Gerry, New York.	1884	1884	do.	61,880 to 68,160	26
Tigass†	do.	301 6	38 0	25 6	1,000	3,530	Lake steamer.	Union Steamboat Co., Buffalo, N. Y.	1884	1885	Chiefly Bessemer.	do.	30.75

* Built by the Pussey & Jones Shipbuilding Co.

† Built by the Harlan & Hollingsworth Co.

‡ Built by Messrs. John Roach & Son.

§ Built by the Union Dry Dock Co.

REPORT ON MILD STEEL.

PART I.

CONSIDERATIONS LEADING TO THE USE OF MILD STEEL IN THE CONSTRUCTION OF THE VESSELS.

We have seen that a certain amount of progress had been made and experience obtained in the use of mild steel as a structural material in the United States, when such use on a large scale for the construction of the hulls of vessels of war was brought into prominent notice by the report of the Advisory Board, convened by the Secretary of the Navy June 29, 1881, to suggest the number and classes of vessels needed for the United States Navy, and commonly known as the first Advisory Board. This Board consisted of fifteen representative officers of the line and *matériel* corps of the Navy, and their report to the Department, November 7, 1881, developed the fact that the use of mild steel for construction of hulls had been carefully considered, as fully discussed as the means of information at the time allowed, and was the chief source of a difference of opinion so strong as to call for a divided report. The large majority of the Board reported favorably to the use of mild steel as a material for the hulls of the larger vessels at that time proposed, as follows:

The most difficult question brought before the Board for its decision has been that of the proper material of construction for the hulls of the vessels of the larger classes. It was at first decided that, since iron shipbuilding is now well developed in the United States, since the excellence and economy of this material for the hulls of vessels has long been indisputably established, and since iron vessels could be built with an absolute certainty that they would fully meet all requirements of efficiency, the Board should recommend iron as the material of construction.

Upon further investigation, however, the Board is of the opinion that, notwithstanding the greater cost of steel as a ship-building material, the lack of experience in the manufacture of steel frames in this country, and the experimental stage that steel shipbuilding is still passing through in Europe, it should be recommended as the material of construction for the hulls of the 15, 14, and 13 knot vessels, for the following reasons:

1st. The great saving realized in weight of hull, which, by making possible the acquirement of equal advantages on reduced dimensions, compensates in a great measure, if not entirely, for the difference in cost between steel and iron.

2d. The increased strength of hull and increased immunity from damage in grounding or in light collisions.

3d. The rapidly increasing success that attends the construction of steel hulls in Europe.

4th. The certainty that steel is in the very near future to almost entirely supplant iron in the construction of vessels.

5th. The impetus that such a step, taken by the Government, would give to the general development of steel manufacture in this country.

6th. The necessity that, when the ships recommended are completed, they shall in all respects be equal to, if not better than, any of their class in foreign navies.

Finally, that for the reputation and the material advantage of the United States it is of prime necessity that in this country, where every other industry is developing with gigantic strides, a bold and decided step should be taken to win back from Europe our former prestige as the best ship-builders of the world.

It is therefore the opinion of the Board that the 15, 14, and 13 knot classes of vessels should be built throughout of steel.

The considerations governing this report are plainly the extended and increasing use of steel for ship-building in Europe, and the belief, though upon no particular or extended evidence, that at least equally good material could be furnished of the necessary shapes and quality by American manufacturers without excessive cost.

While other points of uncertainty as to the new material were advanced in the minority report, it became evident, in subsequent discussion, that the adverse opinion of the three officers of the Construction Corps of the Navy, on the Board, as to the use of steel was based mainly upon the latter consideration, viz, uncertainty as to the ability of the American manufacturers to produce the desired material without excessive cost.*

The difference of opinion which caused a divided report of this Advisory Board was considered lamentable at the time, though possibly in the end it was not to be regretted, because, the matter coming in this shape before the Forty-seventh Congress, the Naval Committee of the House instituted an exhaustive examination as to the relative merits and probable difference of cost of puddled iron and ingot mild steel as constructive materials for ships of war. Prominent ship-builders and iron and steel manufacturers and workers gave evidence before the committee unanimously in favor of the use of mild steel, while actual experiments were made at the Washington navy-yard and conclusive testimony adduced as to the magnificent behavior of the mild steel exclusively used there for the boilers of naval vessels.†

Then followed the conference, above referred to, between the Senate and House Committees and the Advisory Board, at which the dissenting members, with but a single exception, expressed their conviction, in favor of the use of mild steel.

Accordingly the report of the House Committee on Naval Affairs accompanying H. R. Bill 5001, March 8, 1882, contains the following:

MATERIAL.

Your committee have been greatly aided by the report of both majority and minority, and we have felt entirely safe in following their views on all matters in which they agreed.

The only questions they disagreed upon, which in any way affect the report of this committee, are two in number, and are as follows: first, whether steel or iron shall be used in the construction of vessels recommended to be built; second, whether the second size vessel recommended shall be built with open or spar decks.

The first of these questions the committee felt called upon to decide for themselves, and, after carefully taking the opinions of the most extensive and experienced manufacturers of steel and iron in this country whom we could reach, we have unanimously decided that steel should be used instead of iron, and we are of the opinion that if the members of the Advisory Board could have had before them the same evidence as the committee had, and could have been as fully informed as to the progress, extent, and present condition of the manufacture of steel in this country as the committee have been, they would have all united in recommending steel as the only proper material for the construction of vessels of war. We understand that the reason why any advocated the use of iron was because of a doubt whether steel of the requi-

* See "Reconstruction of the Navy," previously referred to, under heading, "Notes of a conference held in the office of the Secretary of the Navy between members of the Senate and House Committees on Naval Affairs, members of the late Advisory Board, and other officers of the Navy," p. 190 *et seq.*

† "Reconstruction of the Navy," H. R. Report No. 653, Forty-seventh Congress.

site quality could be produced in this country in sufficient quantity and at reasonable cost. But on these points there would seem to be no ground for reasonable apprehension, and we recommend steel without hesitation or doubt. The evidence taken by the committee is herewith reported, and we commend it to the consideration of Congress.

The committee were surprised and gratified to learn that the United States is today the second country in the world, if not indeed the first, in the extent of the manufacture of steel, and that steel of American manufacture is better than that made in Europe. Specimens of open-hearth steel (which is the best for ship-building purposes, as the evidence clearly shows) from several of the largest manufacturing in the country were presented to the committee, and may now be seen in the committee-room. This class of steel is uniform in character, and has a tensile strength of from 55,000 to 63,000 pounds to the square inch, and a ductility of 30 per cent. It is capable of being folded cold under heavy hammers without crack or fracture. A portion of the committee visited the navy-yard at Washington for the purpose of witnessing experiments with this class of steel. Specimens taken from the scrap-heap of two different manufacturing, that of Park Brothers & Co., of Pittsburgh, and the Otis Steel Company, of Cleveland, were submitted to the severe test named, and both exhibited equal ductility and strength. Another specimen, from the works of the Norway Iron Company at Boston, of equally good quality, was placed in the hands of the committee, and also specimens from Shoenberger & Co., of Pittsburgh.

Your committee have also before them numerous specimens of iron which has heretofore been used in the construction of vessels. The difference between steel as at present manufactured in this country, adapted for ship-building purposes, and iron, commonly used, is so great and so much in favor of steel that we would commit a great wrong should we leave the question open. As to the kind of steel which this country can produce, including Bessemer steel, we simply have to say that the production is unlimited. With their present facilities, besides supplying the demand for other purposes, it is believed from the evidence before the committee that the manufacturers of open-hearth steel in this country would be able to furnish 100,000 or 200,000 tons per year, superior to any made elsewhere in the world, should the Government demand so great an amount. It appears in the evidence that the Government has abandoned the use of iron for the manufacture of boilers, and for the last four years has made use exclusively of open-hearth steel for that purpose.

We call attention to the statement of Mr. George Wilson, superintendent of machinery at the Washington navy-yard, found on page 129 of the accompanying evidence. Mr. Wilson says:

"If you get a good piece of iron, and it does not break, there is no difference in the cost of working, but in the difficult flanges there is great liability of spoiling the iron. You will spoil about 10 per cent of the iron flanges. You may have men working ten days on a sheet of iron, and then have it spoiled. But we have never spoiled but one sheet of steel. In the many thousands that we have used in the last four years we have spoiled but one; and even that we could have used."

The committee are satisfied that in all respects steel is the best material for ship construction, and we therefore unhesitatingly recommend it.

While the danger of attempting to obtain too great economy of weight by using steel of too high tensile strength and consequent low working quality was made perfectly plain during the investigation, on the other hand it appears to have been thoroughly realized that the strength of the very softest grades was too low to obtain sufficient economy over iron to warrant the more expensive construction, and, in fixing the lower limits of tensile strength and ductility subsequently adopted, Congress was doubtless guided by the evidence before it as to the specifications in use in foreign navies and insurance societies, under which thousands of tons of shipping had been constructed.

The act of August 5, 1882, authorizing the construction of certain new vessels contains the following provision as to material: "Such vessels * * * to be constructed of steel, of domestic manufacture, having as near as may be a tensile strength of not less than 60,000 pounds to the square inch, and a ductility in 8 inches of not less than 25 per centum;" in which it will be observed that the lower limit of tensile strength, 60,000 pounds, or 26.70 tons, per square inch, lies between the 26 tons of the British Admiralty and the 27 tons of Lloyd's Insurance Registry, while the ductility required is one-quarter higher, thus showing the confidence acquired during its investigation, that our steel manufacturers

could produce a higher grade of material than is demanded for ship-building purposes in Europe, a conclusion fully borne out by the results embodied in this report.

The provision as to quality of material contained in the act of August 5, 1882, was continued in the act making appropriations for the naval service, approved March 3, 1883, under which the vessels now building were commenced.

Shortly after the passage of this act, the Board addressed the following circular letter, under date of March 21, 1883, to prominent steel and iron manufacturers relative to their capacity to furnish such material as would probably be required. No detailed information could be at that time furnished, since the designs of the vessels were not in a sufficiently forward state.

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington City, March 21, 1883.

Messrs. ———— :

The Naval Advisory Board, wishing to obtain positive information with regard to the capability of American manufacturers for providing the material necessary for the construction of the unarmored cruisers to be built for the Navy, will be obliged if you will kindly answer the following questions at your earliest convenience.

Can you manufacture, with your present existing plant and appliances, the following specified shapes? The material to be of steel of domestic manufacture, having as near as may be a tensile strength of not less than 60,000 pounds to the square inch, and a ductility in 8 inches of not less than 25 per centum, viz :

ANGLES.

Size.	Weight per foot- length.	Size.	Weight per foot- length.
	<i>Pounds.</i>		<i>Pounds.</i>
2 by 2 inches.....	3½	5 by 3 inches.....	10
2½ by 2½ inches.....	4½	4 by 3 inches.....	10
2½ by 2½ inches.....	5	5 by 3½ inches.....	11
3 by 2 inches.....	7	4 by 3½ inches.....	12
3 by 3½ inches.....	8½	6 by 3½ inches.....	14

T BARS.

4½ by 3 inches	8½
---------------------	----	-------	-------

BULB BEAMS.

6 by 4½ inches.....	18	9 by 5½ inches.....	31
8 by 5 inches.....	23	10 by 5½ inches.....	32
9 by 5 inches.....	27		

Z BARS.

PLATES.

[From 8 to 30 pounds per square foot.]

Weight.	Size.
30-pound plates	5 by 16 feet.
22-pound plates	4½ by 16 feet.

Very respectfully,

R. W. SHUFELDT,
Commodore, U. S. N., President of the Board.

The replies which follow show both willingness and ability to undertake the work, with the exception, perhaps, of the larger deck-beams:

[Oliver Bros. & Phillips.]

PITTSBURGH, April 17, 1883.

DEAR SIR: We are prepared to roll steel plates and bars, and in that view request that you kindly mail us specifications of the sizes and quality of the above material required by the Government in the new vessels ordered by Congress to be constructed.

Yours truly,

OLIVER BROS. & PHILLIPS.

Hon. W. E. CHANDLER,
Secretary of the Navy, Washington, D. C.

[The Nashua Iron and Steel Company.]

NASHUA, N. H., March 23, 1883.

DEAR SIR: Yours of 21st instant at hand and in reply would say that with our present existing plant and appliances we can only manufacture the steel rectangular plates referred to, viz: 8 to 30 pounds per square foot. The 30 pound plates to be 5 by 16 feet; the 22 pound plates to be 4 by 16 feet.

Respectfully, your obedient servant,

J. D. SWAIN, *Superintendent.*

P. S.—We send you by mail to-day a small book giving list of goods we manufacture.

R. W. SHUFELDT,
Commodore, U. S. Navy, President Naval Advisory Board.

[Park, Brother & Co.]

PITTSBURGH, PA., March 24, 1883.

DEAR SIR: We are in receipt of your favor of 21st instant and in reply would say we are not prepared to make angles, T bars, or Z bars.

We are prepared to make bulb beams which we presume are not rolled to shape, and plates of the sizes, dimensions, and quality you require.

We shall be pleased at any time to make you an estimate of price.

Yours truly,

R. W. SHUFELDT, Esq.,
Commodore, U. S. Navy,
President Naval Advisory Board, Washington, D. C.

PARK, BROTHER & Co.

[Carnegie Bros. & Co., Limited.]

PITTSBURGH, March 24, 1883.

DEAR SIR: We are in receipt of your circular letter of 21st March. We are now prepared to roll nearly all the sizes of angles, tees, beams, &c., you specify, of steel. Those we cannot at present make we will have rolls for by the time the material is wanted.

We cannot, however, make plates exceeding 36 inches in width. We note your specification calls for 54 and 60 inch plates.

The steel we propose furnishing will meet all the specified requirements.

We shall be glad to make tender whenever called upon so to do.

Yours respectfully,

CARNEGIE BROS. & Co., LIMITED,
H. P. POPE.

R. W. SHUFELDT,
Commodore, U. S. Navy,
President Naval Advisory Board, Washington, D. C.

[Singer, Nimick & Co., Limited.]

PITTSBURGH, PA., March 23, 1883.

DEAR SIR: We have your favor of the 21st instant to hand; contents noted.

We beg to say in reply, that we are not prepared to make the shaped material your specification before us describes.

Very truly yours,

SINGER, NIMICK & Co., LIMITED,
GEORGE SINGER,
Secretary & Treasurer.

R. W. SHUFELDT,
Commodore, U. S. Navy,
President Naval Advisory Board, Washington, D. C.

11590 M S—2

[A. R. Whitney & Co.]

NEW YORK, *March 26, 1883.*

DEAR SIR: We are not prepared to make the angles, Tees, and Z bars of steel, but can supply the plates. We can, however, supply the shapes of steel from Messrs. Carnegie Bros. & Co., Pittsburgh, to whom you have already applied, and who will quote you direct.

Yours truly,

A. R. WHITNEY & CO.

Commodore R. W. SHUFELDT,
Washington, D. C.

[A. R. Whitney & Co.]

NEW YORK, *April 12, 1883.*

GENTLEMEN: Since writing you we have arranged to make the steel shapes, as inquired for in your favor of 21st instant.

Yours truly,

A. R. WHITNEY & CO.

NAVAL ADVISORY BOARD,
Washington, D. C.

[The Midvale Steel Company.]

PHILADELPHIA, *March 24, 1883.*

DEAR SIR: Your esteemed favor of the 21st instant, regarding steel shapes and plates for ship-building purposes, came duly to hand and we note contents. The matter of rolling shapes from steel received much attention from this company, and in rolling such material for the superstructure and approaches of the Brooklyn Bridge, we made, we believe, the first lot of any amount of steel shapes ever manufactured in this country. Inclosed please find a blue print of the shapes rolled by us for the Brooklyn Bridge, for which we now have the required rolls. The shapes which you require for ship-building purposes, excepting the angles, are quite different from any we have yet manufactured, but we do not think there will be any serious difficulty in their production.

We are now, however, giving the matter our careful consideration; in the course of a few days can speak more clearly upon the subject, when we will again communicate with you. As regards the steel of which such shapes will be made, we think we will have no difficulty whatever in producing, uniformly, a metal showing the physical properties required. Our mill is not now equipped for rolling plates, having been altered to a bar-mill for the purpose of rolling the shape work above referred to. We would always be in a position to furnish hammered blooms of any specified quality of steel for rolling into plates. In manufacturing steel in the open-hearth furnace, it has always been our endeavor to produce certain definite grades, with the greatest possible regularity; and we would have no hesitation in undertaking to produce a thoroughly satisfactory article for ship-building purposes. We will write you more definitely in the near future about the shapes you may require. There would, of course, be no difficulty in rolling the angles.

Very respectfully,

R. W. DAVENPORT,
Superintendent.

R. W. SHUFELDT,
President of Naval Advisory Board, Washington, D. C.

[The Midvale Steel Company.]

PHILADELPHIA, *April 3, 1883.*

DEAR SIR: On looking more carefully into the matter of rolling the deck, or bulb beams, concerning which you inquired in your favor of March 21st, we find that, owing to the great width of flange required in the 8, 9, and 10 inch beams, it will require a very great pressure to bring the flanges up perfectly from a square steel billet or bloom, and we fear that, with the largest mill we have at present (which is a 23-inch mill, about the same size usually employed in rolling rails), we will not be able to do this work. As, however, we are anxious to turn our production in the direction of special steel shapes, we will keep the subject in mind, and will be much obliged if you could let us have a drawing showing the exact sections and shapes of steel bars which will probably be required in ship-building. We could, we think, make the 6-inch deck beams, as well as the angles, T, and Z bars mentioned.

We remain yours respectfully,

R. W. DAVENPORT,
Superintendent.

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[Shoenberger & Co., Juniata Iron and Steel Works.]

PITTSBURGH, March 29, 1883.

DEAR SIR: Your favor of 21st instant came duly to hand and it gives us pleasure to tell you that we are prepared to roll any size steel plate you may require up to 100 inches in width, and at any time will be pleased to name you our lowest prices and give your orders attention.

We do not manufacture angles or bulb beams, which we understand are deck beams, but could easily furnish them to you by having them rolled here by other parties, except the 6 by 3½ angles; for these we could furnish 6 by 4.

We could also have the T bars rolled for you, but instead of 4½ by 3 we could furnish 4½ by 3½. We could also furnish 7, 8, and 9 inch deck beams, but not 6 and 10 inch, and the widest flange for both 8 and 9 inch deck beams is 4 inch, while you specify 5 inch. If, however, you would need a considerable quantity of the shapes, we could have rolls turned specially and furnish all the size shapes you specify.

Hoping we may hear from you when you are in the market,

Yours truly,

SHOENBERGER & CO.

P. S.—We would have answered you more promptly but were delayed in finding out about angles, &c.

Yours,

S. & CO.

R. W. SHUFELDT, Esq.,
Commodore, U. S. N., Washington, D. C.

It should be observed that these replies are by no means a complete measure of the ability of our manufacturers to perform the work, and in fact but one of the above firms, Messrs. Park, Bro. & Co., actually supplied material in any considerable quantity under subsequent contract.

The difficulty of producing the required quality of material does not seem at this time to have received any particular attention, the chief source of uncertainty being as to the rolling-mill capacity for some of the shapes, and whether or not the orders would be sufficiently large to warrant an overhauling of machinery and the manufacture of certain new rolls required.

The production of steel plates for boiler and other purposes had reached sufficient proportions to prevent any difficulty attaching to the mere rolling of the plates required. Several plate mills of 110 inches length between housings were in constant use, and one 120 inches long was available if necessary. Few of the shape mills, however, had any experience in working steel, except as rails, and the sufficiency of strength of the rolls and connections as used for iron was a matter of some uncertainty. The rolling of steel beams of any size had never been attempted so far as we know; certainly the best shapes and arrangement of passes was a matter of discussion and even of patent. At the time of this writing a 12-inch I beam is the largest section produced in steel, and that only in one mill, and from shaped blooms.*

Still there can be no doubt of the willingness of many of the shape manufacturers to undertake any reasonably large order at a price only sufficient to cover the actual cost of production, in order to gain experience and place themselves in a position to meet any subsequent demands. In many places the fact was fully realized that in the near future there would be a rapidly increasing demand for structural steel in shapes necessary for bridge, roof, and ship construction, which is even now the case.

In the matter of quality, the Board, even at this time, recognized the fact that trouble and serious obstruction might be caused by interpret

* Rolled at the works of A. & P. Roberts, Pencoyd, Pa., on a 23-inch mill, from shaped blooms supplied by the Pittsburgh Steel Casting Company.

ing the statute as requiring a ductility of 25 per cent. in 8 inches as a minimum. Only two out of the nine steel manufacturers replying to the circular letter had touched at all upon the quality demanded, and these only in a general way, apparently without definite knowledge and confident that there could be nothing excessive demanded. As no objection had been made to the possible exaction of these requirements as minima, a system of tests was devised accordingly and submitted to the Department with an accompanying letter containing the opinion that these requirements were perhaps higher than necessary to secure good material and suggesting an average ductility of 25 per cent., no single test falling below 23 per cent.

The system of tests as at that time proposed is as follows:

TESTS OF STEEL FOR CRUISERS.

Instructions to inspectors.

The following rules are prescribed in order to insure the fulfillment of the clause of the act of Congress of August 5, 1882. "Such vessels * * * to be constructed of steel, of domestic manufacture, having, as near as may be, a tensile strength of not less than 60,000 pounds to the square inch, and a ductility in 8 inches of not less than 25 per centum":

I. All ship-plates, beams, angles, rivets, bolts, boiler-plates, and stays, to be inspected and tested at the place of manufacture by a naval inspector of material, and to be passed by him, subject to restrictions hereinafter mentioned, before acceptance by the ship-builders, whether Government or private, for incorporation into said vessels.

II. Every plate, beam, and angle, supplied for these vessels, to be clearly and indelibly stamped in two places, and with two separate brands: (1st) With that of the maker, which shall distinguish the name of the manufactory or company. (2d) With the regulation brand of the naval inspector of material. The latter not to be stamped upon any of the above-mentioned material until it shall have passed the required inspection and tests, have been accepted by the inspector, and have been stamped with the maker's brand.

In case of small articles passed in bulk, the above-mentioned brands shall be applied to the boxing or packing material of the objects.

No steel material to be received at the building yards for incorporation into the vessels except it bear, either upon its surface or that of its packing, both of these brands as evidence that it has passed the necessary Government inspection.

SHIP-PLATES.

III. In every lot of 20 plates test pieces to be cut from two plates taken at random; two test pieces being cut from each plate, one in the direction of the rolling, and one at right angles to it, shaped according to the annexed sketch. These test pieces shall in no case be annealed.

The test pieces to be submitted to a direct tensile stress until they break, and in a machine of approved character.

The initial stress to be as near the elastic limit as possible; which limit is to be carefully determined by the inspector in a special series of tests. The first load to be kept in continuous action for five minutes. Additional loads to be then added at intervals of time as nearly as possible equal, and separated by half a minute; the loads to produce a strain of 5,000 pounds per square inch of original section of the test piece until the stress is about 50,000 pounds per square inch of original section, when the additional loads should be in increments not exceeding 1,000 pounds.

An observation to be made of the corresponding elongation measured upon the original length of 8 inches.

The final elongation to be that obtained at rupture. The loads applied shall never be calculated from the indications of the pressure gauge if a hydraulic press be used.

In order to be accepted, a test must show an ultimate tensile strength of at least 60,000 pounds per square inch, and a final elongation in 8 inches of not less than 25 per cent. Plates which show a strength greater than 60,000 pounds per square inch will be accepted, provided the ductility remains at least 25 per cent.

If the average of these four test pieces fall below either of the required limits these plates shall be rejected and another plate from the lot shall be tested; if it fails the lot shall be rejected, and if it is successful a third test shall decide.

QUENCHING TEST.

IV. A test piece shall be cut from *each* plate, angle, or beam, and after heating to a cherry red, plunged in water at a temperature of 82° Fahrenheit. Thus prepared it must be possible to bend the pieces under a press or hammer so that they shall be doubled flat, the two parts being in complete contact with each other, without presenting any trace of cracking.

These test pieces must not have their sheared sides rounded off, the only treatment permitted being taking off the sharpness of the edges with a fine file.

ANGLES, BEAMS, BULB BARS, T BARS, &C.

V. In every lot of 20 angles or beams, &c., test pieces to be cut from the webs of two taken at random, one from each. These pieces to be fashioned in the same way, and to be subjected to the same tests, both tensile and quenching, and to fulfill the same requirements for acceptance as already prescribed for ship-plates.

Angle bars are to be subjected to the following additional tests: A piece cut from one bar in twenty to be opened out flat while cold under the hammer; a piece cut from another bar in the same lot shall be closed until the two sides touch while cold; a piece from a third bar of the lot to be bent cold into a ring so that one of the sides of the angle bar shall be kept flat and the other side forming a cylinder, of which the internal diameter shall be equal to 3½ times the breadth of the side which remains flat. The angle bars submitted to these tests must show neither cracks, cliffs, nor flaws.

Single T bars to be submitted to the following tests: A piece to be cut from the end of a bar taken at random from each lot of 20, and to be bent cold into a half ring, so that the web remaining in its own plane, the cross flanges shall form a half cylinder, of which the internal diameter shall equal four times the height of the web of the T bar.

At the end of another bar of the same lot the web to be split down its middle for a length equal three times its total depth, and a hole drilled at the end of the slit to prevent it spreading; the piece thus split to be opened out in its own plane, so as to make an angle of 45° with the rest, care to be taken that the part opened shall be kept straight, except that it must be joined to the rest of the bar by a band of small radius.

Bulb bars are to be subjected to the same tests as those prescribed for T bars, except that in bending one or more heats may be used.

All bars submitted to these tests must show neither cracks, cliffs, nor flaws.

RIVETS.

VI. One bar from every lot of twenty of the bars from which rivets are made shall be subject to the same tensile test as that required for the plate tests. All bars not fulfilling the requirements of tensile strength and elongation required for plates to be rejected.

From every lot of 500 pounds four rivets are to be taken at random and submitted to the following tests, one rivet to be used for each test: 1st. A rivet to be flattened out cold under the hammer to a thickness of one-half its diameter without showing cracks or flaws. 2d. A rivet to be flattened out hot under the hammer to a thickness one-third its diameter without showing cracks or flaws. 3d. A rivet to be bent cold into the form of a hook with parallel sides without showing cracks or flaws. 4th. A rivet to be tested by shearing by riveting it up to two pieces of steel which are to be submitted to a tensile strain, the rivet not to shear under a stress of less than 50,000 pounds per square inch.

BOILER PLATES.

VII. *Each* boiler plate must be subjected to the same tests and in the manner prescribed for ship-plates. The ductility in 8 inches must not be less than 25 per cent., and the ultimate tensile strength must not be less than 57,000 pounds and not more than 63,000 pounds, and the average at least 60,000 pounds.

The acceptance of material under these tests will not relieve the contractor from the necessity of making good any material which fails in working or may be rejected by the inspector.

But before finally adopting this system of tests, it was deemed expedient to place it before various ship-builders and steel manufacturers interested for criticism and suggestion, especially as the probability of the vessels being built by contract was very strong, in which event too

much time could not be allowed intended bidders to arrive at a definite and satisfactory understanding as to their supply of material.

Accordingly copies of the preliminary scheme of tests were sent out with accompanying letter :

NAVAL ADVISORY BOARD,
Washington, April 30, 1883.

Messrs. ——— :

The following tests inclosed herewith have been prepared in order to insure the fulfillment of the provisions of the act of Congress of August 5, 1882, relating to the construction of steel cruisers.

The Board will be glad to receive any suggestions from you before the final adoption of these rules.

Very respectfully,

R. W. SHUFELDT,
Commodore, U. S. Navy, Pres. Naval Advisory Board.

Replies came in slowly, as follows :

[The Harlan and Hollingsworth Company.]

WILMINGTON, DEL., May 1, 1883.

SIR: We beg to acknowledge the receipt of your communication of the 30th ultimo, with inclosure of "Instructions to Inspectors" regarding tests of steel for cruisers.

The matter shall have our careful attention.

We are, very respectfully, yours, &c.,

J. T. GAUSE,
Vice-President.

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[The Pusey & Jones Company.]

WILMINGTON, DEL., May 2, 1883.

DEAR SIR: We have your favor of 30th ultimo, with inclosure of memorandum of tests which it is proposed to apply to the materials to be used in the construction of the new steel cruisers.

In a very few days we shall have the pleasure of submitting our views regarding them.

Very respectfully,

PUSEY & JONES CO.,
By W. G. GIBBONS, Pres.

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[Black Diamond Steel Works. Park, Brother & Co.]

PITTSBURGH, May 5, 1883.

DEAR SIR: Your printed circular, inclosed under date of April 30, marked "Tests of Steel for Cruisers," came duly to hand and contents noted.

Thanking you for this copy of "Instructions to Inspectors," we beg to advise you we have no suggestion to submit, and subscribe ourselves,

Very truly,

PARK, BROTHER & CO.

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[The Pusey and Jones Company.]

WILMINGTON, DEL., May 8, 1883.

DEAR SIR: We confirm our advices of 2d inst.; and now further referring to your circular letter relative to the tests which it is proposed to apply to the steel to be used in the construction of the vessels called for under act of Congress of August 5, 1882, we have to say that in our opinion a measure of ductility of 25 per cent. in 8 inches is incompatible with a tensile strength of 60,000 pounds to the square inch.

The very best grades of "fire-box steel" will, under favorable circumstances, show a measure of ductility as above; but it is not often found having so high a degree of tensile strength as 60,000 pounds when associated with so great a ductility.

We are further of opinion that in view of the difficulties attending the tests as described in the afore-mentioned circular letter—that is to say, in producing steel of a grade that will stand the tests successfully—very few of the steel manufacturers of this country would wish to undertake the task of furnishing the plates and bars required, even with the inducement of a price much above the ruling rate for ship plates.

It is unfortunate that Congress has so fenced in the testing of the materials as to make the procuring of them almost impossible, because steel can be had, possessing a less measure of ductility, that would endure all the strains that are likely to be applied to the ships in question. If we can serve you further please command us.

Yours truly,

THE PUSEY & JONES CO.,
By W. G. GIBBONS, *President.*

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[The Midvale Steel Company.]

PHILADELPHIA, May 26, 1883.

DEAR SIR: The Board's circular letter of April 30, regarding the proposed tests of steel for cruisers, came duly to hand. We have considered the matter with care, and think that the tests prescribed should certainly insure a first-rate quality of steel for the purpose in question.

The only criticism we have to make is in the test prescribed for boiler plate, which, when compared with the ship-plates in the matter of extensibility, appears to us to be too low; and we think boiler-plates showing a tensile strength of from 57,000 to 60,000 pounds per square inch should show a greater extension than 25 per cent.

Respectfully, yours,

R. W. DAVENPORT,
Superintendent.

Commodore R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Washington, D. C.

[Army and Navy Supplies. Austin P. Brown, agent.]

WASHINGTON, D. C., June 6, 1883.

SIR: We have the honor to say, in answer to your letter of April 30, ultimo, regarding steel for new cruisers, that we have no suggestions to make regarding the printed instructions to inspectors inclosed therein, as, in our opinion, they are as perfect as is possible to make them.

Permit us to say in this connection that we are prepared to furnish ship and boiler plate, to stand the required tests, at the rate of from 50 to 75 tons per day.

Your letter was laid aside as not requiring an answer, and our only reason now for replying is that we are informed that you have not received all the information you desire regarding the ability of manufacturers to furnish the steel up to the full standard required by law, as regards tensile strength and elongation.

Very respectfully, your obedient servants,

OTIS IRON AND STEEL CO.,
By AUSTIN P. BROWN, *Agent.*

Admiral R. W. SHUFELDT, U. S. N.,
President Naval Advisory Board, Navy Department, Washington, D. C.

[The Harlan and Hollingsworth Company.]

WILMINGTON, DEL., June 7, 1883.

DEAR SIR: We have corresponded with all the manufacturers of steel in the United States regarding the tests required by the Naval Advisory Board for the steel to be used in the new cruisers, and we are clear in the conviction that the rule for 60,000 pounds tensile strength and an elongation of 25 per cent. in 8 inches cannot be adhered to.

There are very few makers of steel that admit that they can make steel to stand these tests.

The few who do admit it say that such steel will cost a great deal more money than if the tests were less severe.

Now, we fear that the difficulty will be that those parties who may obtain contracts for building these cruisers will have to pay an exorbitant price for the steel because of the severity of the tests in question.

We would suggest, to meet the difficulty, that the tensile strength be put at from

55,000 to 62,000 pounds per square inch, and that the elongation should be from 20 to 25 per cent. in 8 inches.

With this modification we believe the builders of the cruisers will be able to get steel at satisfactory prices, and from a sufficient number of makers to meet their requirements, and avoid any unnecessary delay in obtaining their materials.

Unless the tests were modified in the manner suggested, we should feel considerably embarrassed in making our bids.

Yours, &c.,

J. TAYLOR GAUSE,
President.

Hon. W. E. CHANDLER,
Secretary of the Navy, Washington, D. C.

P. S.—The following is copy of letter received, and which is a fair sample of the replies from the different makers:

"While we are prepared to make steel suitable for the purpose mentioned, yet we are not prepared to make steel that will show a uniform test of 60,000 pounds tensile strength, and a ductility of 25 per cent. in 8 inches.

"We can make steel with the ductility required, but it will not pull 60,000. Practically, steel required to have a ductility of 20 per cent. in 8 inches should range from 55,000 to 65,000, and 25 per cent. from 48,000 to 58,000.

"The Pennsylvania Railroad Company's test for boiler plate is about as good and practical as any we know of, and if, with their long experience, it is found all right for boiler plate, it ought to answer for ship plate.

"SINGER, NIMICK & CO., LTD."

[Shoenberger & Co.]

PITTSBURGH, June 9, 1883.

DEAR SIR: Will you have the kindness to let us know regarding the matter of steel plates for steel cruisers? When will the matter be decided, and when are the contracts to be let for the plates? Your reply will greatly oblige,

Yours truly,

SHOENBERGER & CO.

Commodore R. W. SHUFELDT, U. S. N.,
Washington, D. C.

[Park, Brother & Co.]

PITTSBURGH, PA., June 14, 1883.

DEAR SIR: We do not think we were definite enough in our letters to you regarding quality of steel, and now write to say that we are prepared to furnish steel to stand the required test; that is, 60,000 pounds tensile strength with an elongation of 25 per cent. in an 8-inch section.

We have heard recently that your Board had under consideration the propriety of reducing the requirements and making the elongation 20 per cent. instead of 25 per cent., but we can assure you of our ability to give you steel which will stand the maximum test.

Very respectfully,

PARK, BROTHER & CO.

R. W. SHUFELDT, Esq.,
Commodore U. S. Navy,
President Naval Advisory Board, Washington, D. C.

It is seen from these replies that while most of the steel manufacturers showed willingness to supply the material demanded, the shipbuilders expressed strong doubts as to the necessary certainty in manufacture and fears of excessive cost.

In order to arrive at a perfectly definite and satisfactory conclusion on this subject, it became necessary to undertake a complete investigation. If it should be found that the particular provision of the law, as regards tensile strength and ductility, could not be held to as lower limits (the view which had hitherto been taken of it) without serious difficulty, cost, and probable delay, then, under the authority of the phrase "as near as may be," such modifications could be made as to remove the practical difficulties while obeying the spirit of the law's requirements. Accordingly the following letter was addressed to the De-

partment, recommending a reduction of the ductility requirement to 20 per cent., for the reasons given:

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington City, June 11, 1883.

SIR: Referring to our letter to the Department of 26th April, suggesting tests for steel, it was stated therein "the Board considers that the ductility required by law is perhaps higher than is necessary to insure good material, and will consider whether or not tests will be accepted as satisfactory which show an average ductility of 25 per cent., provided no actual test falls below 23 per cent."

In the formulation of these tests the Board considered the law as prescribing certain fixed lower limits of strength and ductility for the hulls of the vessels, and acted accordingly, though quite aware, as indicated in the above paragraph, that the test required was more severe than is demanded by foreign navies and registration societies.

The Board now learns that though the class of material has not been commonly produced in this country, still, as shown by the letters of steel companies, inclosed, it can be manufactured.

The Board is, however, of the opinion that a first-class material would be obtained by reducing the ductility to 20 per cent., that a possible delay in construction will be thus avoided, and a considerable reduction in the total cost of the vessels obtained.

If the Department authorizes this reduction, the Board recommends that the tests as thus amended, including a minor change in the quenching test, which follows necessarily upon a reduction in ductility, be inserted in the contracts.

Very respectfully,

R. W. SHUFELDT,

Rear-Admiral, U. S. N., President Naval Advisory Board.

Hon. W. E. CHANDLER,
Secretary of the Navy.

In reply, the honorable Secretary of the Navy expressed a wish to see the tests so arranged that the builders would not be at the mercy of a few steel-makers, as they feared, but considered a reduction of the ductility requirement to 20 per cent. as too great a variation from the statute, and suggested 60,000 pounds and 23 per cent. as the limits for the average of four test-pieces, with a recommendation that a lower limit of tensile strength and ductility be determined, below which no single test should fall, and suggesting 58,000 pounds and 21 per cent. for these limits.

Mr. Charles Cramp, one of the most prominent ship-builders, happening to attend soon after, stated his satisfaction with the requirements so changed and that a reduction in price would result. Under the first requirements he could obtain no quotations from makers, while in demanding under the Admiralty requirements he obtained ready replies.

The subject was again fully investigated, and, in order to appreciate the considerations governing the modifications subsequently made in the requirements as to tensile strength and ductility of ship material, it becomes necessary to follow out the comparison made with those in general use in Great Britain and France,* as given *in extenso* in the appendix. It will suffice to state them here in general terms with reference to the opposite graphic table.

REQUIREMENTS FOR MATERIAL IN GREAT BRITAIN.

British Admiralty requirements.—A tensile strength of 26–30 tons per square inch, with a ductility of 20 per cent. in 8 inches.

Lloyd's Insurance Registry.—A tensile strength of 27–31 tons per square inch, with a ductility of 20 per cent. in 8 inches.†

* The original French requirements are not given in the Appendix, but only those now in force. They may be sufficiently understood from the graphic table.

† Lloyd's Registry within the last few years has sanctioned a reduction of ductility to 16 per cent. in 8 inches, which is now incorporated in the "Rules." (See Appendix, page 574.)

Liverpool Underwriters' Registry.—A tensile strength of 28–32 tons per square inch, with no requirement as to ductility except that indirectly imposed by the ordinary temper and bending test.

These requirements are all extremely simple, and are supplemented by cold bending tests after heating the specimens to a red heat and suddenly cooling them in water, with such other special tests as may be desired by the inspector. The admiralty requirements had been in force since 1875, though the higher limit of tensile strength was not now rigidly adhered to. Lloyd's requirements were issued in 1877.

REQUIREMENTS OF THE FRENCH NAVY.

Although issued in May, 1876, these requirements show a thorough and masterly knowledge both of the properties of the material and of the suitable variation of quality for different parts of the structure. Nor does their apparent lack of simplicity involve any proportionate increased cost. Thus, if we should start with a sufficiently thick ingot and roll it down, at one heat, to plates of successively diminishing thickness, removing test-pieces, at each thickness within the range contained within the requirement for ship-plate, they would show successively increasing tensile strength and diminishing ductility, following very much the same law as the minimum requirements; for the plate of each successive thickness has more work on it, is finished at a lower heat, and cools more rapidly than its predecessor.*

If our ingot be not sufficiently thick, the greatest thickness will not have the greatest ductility, on account of insufficient work to remove the effects of honeycombing or blow-holes. A corresponding humoring of the difficulties of manufacture is seen in the requirements for the heaviest boiler plate, for which both less tensile strength and less ductility are required than in the next less range of thickness. For strips and straps higher tensile strength and ductility are required than for the plates which they are to connect, which is plainly in accordance with increased strength of the whole structure. For beams the tensile strength is higher and ductility lower than for plates, indicating the proper use of a somewhat harder and ultimately stiffer material. Lastly, for angles, which always have a large amount of work of reduction from the ingot and yet cool in masses, and are thereby more or less annealed, a higher tensile strength and ductility is required than for plates—qualities which would naturally be obtained in the ordinary processes of manufacture, starting from the same material in the ingot, and which are also desirable for the purposes of corner connection and stiffening served by these shapes. Under these requirements, then, the difficulties of manufacture and the efficiency of the material in the structure are, in the main, reconciled and fit into one another without friction. It is seen, therefore, that these requirements admit of complete analysis and show an excellent balance in the quality of material for each purpose served. It should also be remembered that the Siemens-Martin process, by which the mild steel first used in the French navy was exclusively produced, had received its earliest development in France, while an experience of three years had been obtained in the dock-yards be-

* But these qualities also promote efficiency of the structure, inasmuch as the thicker plates, being generally in the skin plating (not the bottom plating, for the French, at that time, from considerations of corrosion, used iron for the wetted skin) or the notched stringer-plates, and from their very thickness suffering more in the working, evidently require to be softer than deck plating, which is not exposed in collision like skin plating, or than light bracket or bulkhead plating, whose chief requirement is stiffness.

fore the adoption of these requirements. Whence it would appear that they could not be too severe for good material, and might be taken as a reasonable minimum, although somewhat above the English specifications.*

MODIFICATIONS OF THE TESTS AS FIRST DRAWN UP.

The highest English specification with a ductility limit imposed was Lloyd's—a tensile strength of 60,480 pounds to the square inch, with a ductility of 20 per cent. in 8 inches. The most severe of the French requirements for ship-plate was 45 kilograms per square millimeter—63,990 pounds to the square inch—with a ductility of 20 per cent. in 200 millimeters.†

The material supplied to both must be more or less uniformly above requirements, and was produced without difficulty by European manufacturers. There could be nothing excessively severe in a requirement, based on that of the French navy, of a minimum tensile strength of 60,000 pounds to the square inch, with a corresponding increase of ductility from 20 to 23 per cent., while the average results of material made to such specifications would reach, and probably exceed, the requirements of the law in the quality of ductility.

Besides, it had always been the proud boast of American manufacturers that their iron was far superior to that in general use in Europe, and it was confidently stated that American steel deserved the same reputation.

With a change in the quenching test corresponding to the diminished ductility demanded, the final programme of tests was drawn up and approved June 18, 1883, as follows:

TESTS OF STEEL FOR CRUISERS.

Instructions to Inspectors.

NAVY DEPARTMENT,
Naval Advisory Board, June 18, 1883.

The following rules are prescribed in order to insure the fulfillment of the clause of the act of Congress of August 5, 1882—"Such vessels * * * to be constructed of steel, of domestic manufacture, having, as near as may be, a tensile strength of not less than sixty thousand pounds to the square inch, and a ductility in eight inches of not less than twenty-five per centum":

I. All ship-plates, beams, angles, rivets, bolts, boiler-plates, and stays to be inspected and tested at the place of manufacture by a naval inspector of material, and to be passed by him, subject to restrictions hereinafter mentioned, before acceptance by the ship-builders, whether Government or private, for incorporation into said vessels.

II. Every plate, beam, and angle supplied for these vessels to be clearly and indelibly stamped in two places, and with two separate brands: (1) With that of the maker, which shall distinguish the name of the manufactory or company; (2) with the regulation brand of the naval inspector of material. The latter not to be stamped upon any of the above-mentioned material until it shall have passed the required inspection and tests, have been accepted by the inspector, and have been stamped with the maker's brand.

In case of small articles passed in bulk, the above-mentioned brands shall be applied to the boxing or packing material of the objects.

No steel material to be received at the building yards for incorporation into the vessels except it bear, either upon its surface or that of its packing, both of these brands, as evidence that it has passed the necessary Government inspection.

* The French requirements, as recently modified by the ministerial circular of February 9, 1885 [see Appendix pp. 570-573], are in closer accord with the requirements adopted by the Board.

† 8 inches = 203.2 millimeters.

SHIP-PLATES.

III. In every lot of twenty plates test pieces to be cut from two plates taken at random; two test pieces being cut from each plate, one in the direction of the rolling and one at right angles to it, shaped according to the annexed sketch. These test pieces shall in no case be annealed.

The test pieces to be submitted to a direct tensile stress until they break, and in a machine of approved character.

The initial stress to be as near the elastic limit as possible; which limit is to be carefully determined by the inspector in a special series of tests. The first load to be kept in continuous action for five minutes. Additional loads to be then added at intervals of time as nearly as possible equal, and separated by half a minute; the loads to produce a strain of 5,000 pounds per square inch of original section of the test piece until the stress is about 50,000 pounds per square inch of original section, when the additional loads should be in increments not exceeding 1,000 pounds.

An observation to be made of the corresponding elongation measured upon the original length of 8 inches.

The final elongation to be that obtained at rupture. The loads applied shall never be calculated from the indications of the pressure-gauge if a hydraulic press be used.

CONDITIONS OF ACCEPTANCE.

In order to be accepted the average of the four test pieces must show an ultimate tensile strength of at least 60,000 pounds per square inch of original section, and a final elongation in 8 inches of not less than 23 per cent.

Lots of materials which show a strength greater than 60,000 pounds per square inch will be accepted, provided the ductility remains at least 23 per cent.

CASES OF FAILURE.

If the average of these four test pieces, numbered 1, 2, 3, 4 (called Test I.), fall below either of the required limits, the plates from which pieces 1, 2, 3, 4 were cut shall be rejected, and Test II. made, consisting of pieces 5 and 6, cut from a third plate. If the mean of the results of these two fall below either of the above limits, the entire lot shall be rejected. If it be successful, Test III., or the mean of pieces 7 and 8, cut from a fourth plate, shall decide.

If in any of Tests I., II., III. any single piece shows a tensile strength less than 58,000 pounds or a final elongation less than 21 per cent., the plate from which it was cut shall be rejected and that test considered to have failed, regardless of its average.

QUENCHING TEST.

IV. A test piece shall be cut from *each* plate, angle, or beam, and, after heating to a cherry red, plunged in water at a temperature of 82° Fahrenheit. Thus prepared it must be possible to bend the pieces under a press or hammer so that they shall be doubled round a curve of which the diameter is not more than one and a half times the thickness of the plates tested without presenting any trace of cracking.

These test pieces must not have their sheared sides rounded off, the only treatment permitted being taking off the sharpness of the edges with a fine file.

ANGLES, BEAMS, BULB BARS, T BARS, ETC.

V. In every lot of twenty angles or beams, &c., test pieces to be cut from the webs of two taken at random, one from each. These pieces to be fashioned in the same way and to be subjected to the same tests, both tensile and quenching, and to fulfill the same requirements for acceptance as already prescribed for ship-plates.

Angle bars are to be subjected to the following additional tests: A piece cut from one bar in twenty to be opened out flat, while cold, under the hammer; a piece cut from another bar in the same lot shall be closed until the two sides touch, while cold; a piece from a third bar of the lot to be bent cold into a ring, so that one of the sides of the angle bar shall be kept flat and the other side forming a cylinder, of which the internal diameter shall be equal to three and a half times the breadth of the side which remains flat. The angle bars submitted to these tests must show neither cracks, cliffs, nor flaws.

Single T bars to be submitted to the following tests: A piece to be cut from the end of a bar taken at random from each lot of twenty, and to be bent cold into a half-ring, so that, the web remaining in its own plane, the cross-flanges shall form a half-cylinder, of which the internal diameter shall equal four times the height of the web of the T bar.

At the end of another bar of the same lot the web to be split down its middle for a length equal three times its total depth, and a hole drilled at the end of the slit to prevent it spreading; the piece thus split to be opened out in its own plane, so as to make an angle of 45° with the rest, care to be taken that the part opened shall be kept straight, except that it must be joined to the rest of the bar by a bend of small radius.

Bulb bars are to be subjected to the same tests as those prescribed for T bars, except that in bending one or more heats may be used.

All bars submitted to these tests must show neither cracks, cliffs, nor flaws.

RIVETS.

VI. One bar from every lot of twenty of the bars from which rivets are made shall be subject to the same tensile test as that required for the plate tests. All bars not fulfilling the requirements of tensile strength and elongation required for plates to be rejected.

From every lot of 500 pounds four rivets are to be taken at random and submitted to the following tests, one rivet to be used for each test: First, a rivet to be flattened out cold under the hammer to a thickness of one-half its diameter without showing cracks or flaws; second, a rivet to be flattened out hot under the hammer to a thickness one-third its diameter without showing cracks or flaws; third, a rivet to be bent cold into the form of a hook with parallel sides without showing cracks or flaws; fourth, a rivet to be tested by shearing by riveting it up to two pieces of steel which are to be submitted to a tensile strain, the rivet not to shear under a stress of less than 50,000 pounds per square inch.

BOILER-PLATES.

VII. *Each* boiler-plate must be subjected to the same tests and in the manner prescribed for ship-plates. The ductility in 8 inches must not be less than 25 per cent., and the ultimate tensile strength must not be less than 57,000 pounds and not more than 63,000 pounds, and the average at least 60,000 pounds.

The acceptance of material under these tests will not relieve the contractor from the necessity of making good any material which fails in working or may be rejected by the inspector.

R. W. SHUFELDT,
Rear-Admiral, U. S. Navy, President Naval Advisory Board.

Approved:
WILLIAM E. CHANDLER,
Secretary of the Navy.

With these provisions as regards material incorporated in the specifications under which bids were tendered, contracts were made with Mr. John Roach, representing the Delaware Iron Shipbuilding and Engine Works, Chester, Pa., and the Morgan Iron Works, of New York, on the 23d day of July, 1883, for the construction of the hulls of the Dolphin (1,500 tons), and Atlanta and Boston (3,000 tons each) and on July 26th for the Chicago (4,500 tons displacement).

PART II.

About the middle of August the first orders for material were issued from the ship-yard, and shortly after, the Board was notified by the contractor that subcontracts had been entered into with the Chester Rolling Mills, Chester Pa., Norway Iron and Steel Company, South Boston, Mass., Park Bros. and Co., Pittsburgh, Pa., for ship and boiler plate, and with the Phoenix Iron Company, Philadelphia, Pa., for angles, tees, and deck beams. Accordingly, on the 29th of August, Lieut. F. J. Drake, U. S. N., was ordered to visit Chester, Phoenixville, and Boston, to report upon the facilities afforded for carrying out the tests at each place, and to assume the duties of inspector at the latter. The facilities for testing appearing satisfactory, inspectors were ordered to each of the above-mentioned works, and to Pittsburgh, at the end of the first week in September, by which time it was expected that the manufacturers would be ready to turn out material. In addition to the general "Instructions to Inspectors" (p. 27), the following detailed instructions were issued:

DETAILED INSTRUCTIONS TO INSPECTORS OF MATERIALS.

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington, September 13, 1883.

(1) The inspector will, as soon as practicable, after reaching his post, carefully examine all the appliances available for the proper inspection of material, consult with the superintendent as to making the tests, and make a special report to the Advisory Board of the kind and the efficiency of the apparatus and the arrangements which have been decided upon for making the different tests.

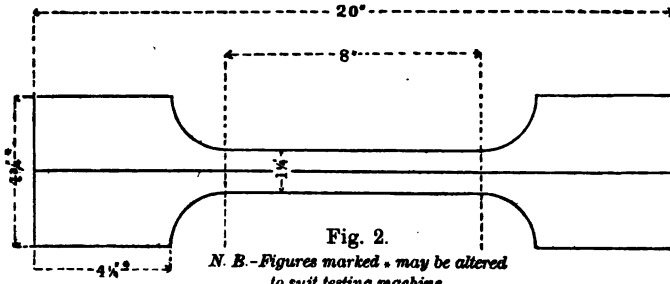
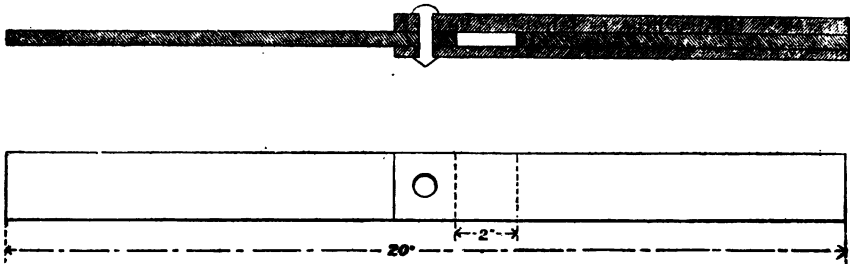
(2) At the end of each week he will make a general report to the Advisory Board of the work done at the foundry during the week, together with such information or suggestions as he may deem necessary in carrying out the work of inspection. At the end of each month he will send to the Advisory Board a summary of the tests made during the month, the summary being drawn up in accordance with the form hereto attached.

(3) He will keep a complete record of every piece of metal tested for the Government and for use in the construction of the new cruisers, whether such piece fulfills the requirements of a successful test or not.

(4) In case of any disagreement connected with the inspection of material, between the inspector and the superintendent of the foundry, the matter in dispute will be referred at once to the Advisory Board for settlement. It will be borne in mind that the Government has no contract with the foundry and exercises no control whatever beyond the actual inspection and stamping of the material; whilst, therefore, the inspection must at all times be strict, every effort must be made by the inspector to have it carried on with the least possible interference or delay. The superintendent of the foundry will be consulted as to the times when the different tests should be made, and also with regard to any modifications in the system or appliances. The inspector will not attempt to exercise any control whatever over either the method of manufacture or the deliveries of material.

(5) The inspector will not permit the Government mark to be placed on any material or package intended for use elsewhere than in the building of the new cruisers, nor will he permit it to be placed on any material or package that has not been inspected by him personally and fulfilled the requirements of inspection.

(6) Whilst the inspector is to use his judgment with regard to the part of the material from which the test pieces are taken, he will in no case, except by the request or by the permission of the superintendent of the foundry, intrench upon the finished measurements of the piece in cutting his test pieces. Tests from pieces of the scrap may be made, and if they fulfill the requirements the article will be passed. If they fail to meet the requirements, however, the piece will not thereby be condemned. All condemnations of material will be made on the failure of pieces taken from the body of the material, and the superintendent of the foundry will be notified at once

Tensile test specimen.*Rivet shearing test specimen.*

Width of plate to be not less than three times the diameter of the rivet. The inner end of the filling piece between the plates not to have an open space of more than 2 inches between it and the end of the single plate.

whenever a piece is condemned, and he will be given free access to the entire record of the test.

(7) Certain test pieces, after being tested, will be marked and carefully preserved, in such a manner and place as to be readily accessible in case of necessity for a subsequent examination or comparison. These retained test pieces will consist of: all those tested for strength and elongation; all of those used in the quenching test which are cut from the same pieces of material as the tensile pieces; all rivets and sheared rivet samples; all pieces whose tests may give rise to dispute or protest on the part of either the inspector, the manufacturer, or the building contractor; such other pieces as the manufacturer may desire to have retained.

(8) Each retained test piece will have a register mark to distinguish it, which mark will be put upon the test piece itself, painted on the proper piece of material in small characters near the Government stamp, and will form a part of the inspector's record.

(9) The register mark will consist of a number and a letter, the number to denote the lot of material, and the letter the piece in the lot. Lots of material will be numbered consecutively in the order in which they are inspected, without regard to the description of the material. As each lot consists of twenty pieces, the individual pieces will be denoted by the first twenty letters in the alphabet. In marking the tensile test pieces which are cut across the grain of the material, a small cross (x) will be affixed to the register mark. The register mark of rivet bars and rivet test pieces will consist of the lot number alone.

(10) In case that the tensile pieces are cut from the material by punching, a margin of not less than one-eighth of an inch will be left between the shoulders of the test piece, which will be removed by the file, plane, or other smooth-cutting tool, in shaping and trimming the piece. This precaution need not be followed if the piece be cut out by planing, drilling, or sawing. In the accompanying sketch of the tensile test piece the width of the breaking section is fixed at $1\frac{1}{2}$ inch. If, however, the thickness of the test piece exceeds one-half inch, the width of the breaking section will be reduced to 1 inch, and if the thickness exceeds three-fourths of an inch, the width will be reduced to the thickness of the section.

(11) In making the tensile test, it will be borne in mind that the establishment of the elastic limit is of secondary importance; therefore no attempt need be made to get it with exactitude, although care should be taken that the first stress applied to the test piece shall be below its elastic limit.

(12) Owing to the possibility of the existence of faults in the different types of testing machines that may be used at the different factories, the tensile strength and elongation records will be checked by comparison with records from Washington. To accomplish this result, the inspector will, as soon as practicable after reaching his post, have four tensile specimens prepared from a single piece of steel, chosen with special regard to homogeneity of structure. These pieces all to be cut with the grain of the material, the width of the breaking section to be one inch and its area not greater than one-half of a square inch. Two of these specimens will be carefully tested in the machine as follows: The first weight applied to give a stress of 10,000 pounds to the square inch. At intervals of one minute an additional stress of 2,000 pounds per square inch of original section will be applied until the specimen is broken. Careful measurements will be made of the elongations caused by each stress. The two other specimens (finished at the foundry exactly like the first), together with the pieces of the broken specimens and a complete record of the tests, will then be forwarded together to the president of the Naval Advisory Board at Washington, where the tests will be checked by a Rodman testing machine.

(13) No piece used in the quenching test will be less than 10 inches in length and 2 inches in width. In bending a piece the inspector will not permit any nursing on the one hand or unfairly violent treatment on the other. If bent under the hammer, the blows should be delivered square to the surface. In all cases uniformity of treatment should be observed. If practicable it would be of advantage to have the same hammer-men do all the quenching test work.

(14) In testing the shearing strength of rivets, the test piece is to consist of a double lap-joint with a single rivet arranged as shown in the accompanying sketch. The plate-steel used is in no case to be less than one-fourth of an inch in thickness, and, if practicable, it should not in any case be less than one-half the diameter of the rivet, in order to insure shearing the rivet instead of the plate. The distance of the nearest edge of the rivet hole to the end of the plate is not to be less than one and one-fourth diameters of the rivet. The sharp edges of the rivet hole are not to be filed down. Snap-riveted points will in no case be allowed in the tests, but invariably the point will be thoroughly and carefully worked down. The rivet holes may be either punched or drilled as desired, and the riveting may be either by hand or machine. Great care will be exercised in testing the sample to insure a fair stress on the rivet.

(15) All instruments, books, and stationery required for use in the inspection will be procured by requisition on the Advisory Board, and receipts will be rendered to the Board for all material received. Postage and telegraph expenses will only be reimbursed through bills made to and approved by the Advisory Board. Expenses for travel will only be reimbursed by the ordinary naval rule of mileage on orders from the Department. Unless absolutely impracticable, no official expense will be incurred by the inspector without preliminary authority from the Advisory Board.

(16) The inspector will be charged with ascertaining the average weight per foot of plate ordered, which will be obtained by weighing not less than 10 tons at a time when larger lots than 10 tons are delivered. In smaller deliveries than 10 tons, the whole lot will be weighed. The plates will be estimated by weight per superficial foot. The weight named will always be the greatest that will be allowed. For ship and boiler plates under 4 feet in width, a latitude of 5 per cent. below this will be allowed in plates one-half of an inch and upwards in thickness, and 10 per cent. in thinner plates. In plates for boilers over 4 feet wide and one-half of an inch thick and upwards a latitude of $2\frac{1}{2}$ per cent. above and $2\frac{1}{2}$ per cent. below will be allowed for the springing of the rolls, and 5 per cent. above and 5 per cent. below will be allowed in thinner plates over 4 feet wide.

The inspector will consult the foundry order book for detailed information and will accept its weights and measurements as authority.

R. W. SHUFELDT,
Rear-Admiral, U. S. N., President, Naval Advisory Board.

Approved:
EARL ENGLISH,
Acting Secretary of the Navy.

Although numerous preliminary tests had been made, considerable delay was caused at first at the plate-mills by failure to meet the requirements. At Chester and South Boston there was such fear of not obtaining the required ductility that there was a decided tendency to make a steel of too low tensile strength, a tendency further increased at the former works on account of the mode of rapid testing with short test pieces which had been hitherto in use; and even with steel so soft the inspectors reported trouble with the quenching or temper test. At South Boston the difficulty was apparently found in the heating of the slabs before entering the plate-rolls, while considerable difference was found in the results of material from different parts of the same ingot, as given in detail, p. 166 *et seq.* At both mentioned works differences in temper tests were reported according as the pieces were heated in an ordinary heating furnace, a charcoal furnace without blast, or in a smith's fire with blast. These difficulties were by degrees overcome, both by greater care at the melting and heating furnaces and increasing familiarity with the tests. At the Chester Rolling Mills trouble was also reported in consequence of the requirements for strength and ductility across the grain, and some delay was caused by lack of system in carrying out the tests, while considerable opposition was experienced on account of somewhat too strong preconceived opinions as to the propriety of the requirements and the method of tests on the part of those having to do with the work. The first shipment was made from these works September 20, and from Boston September 26, and thereafter with considerable regularity.

At the Black Diamond Works, Pittsburgh, the work proceeded very slowly on account of the extreme caution of the manufacturers. Each heat was subjected to a preliminary test, and only such as appeared satisfactory were submitted to the inspector. Then, from some inexplicable cause, except that considerable lack of homogeneity was developed by the tensile tests, much of the material would not stand the quenching test, and it was not until October 10 that the first shipment was made.

At the Phoenix Iron Works, Phoenixville, Pa., there was no steel

plant, blooms to the required specification being supplied by the Cambria Iron Company, with works at Johnstown, Pa., about 250 miles distant, on the Pennsylvania Railroad. Although the first order from the shipyard had been received August 17, no blooms were received until a month later, September 17, though no particular difficulty appears to have been experienced in supplying the proper quality of steel at Johnstown. But, from temporary causes, the blooms were a week to ten days in traversing the distance between the two places, and considerable time was consumed in the necessary handling. Then, in endeavoring to carry out the tests, the small steam-hammers available were found inadequate for the ring test for angles, which had accordingly to be made at Chester, so that the first shipment was not made until September 28.

In consequence of the delays above mentioned, complaints were made by the contractor that on account of the severity and method of the tests, and consequent slow delivery of material, idle men and tools and empty slips were subjecting him to great additional expense. For a time determined efforts were made to break down the system of tests on the score of impracticability and expense, and it is to be regretted that these objections should have been urged as the cause of delays really due to tardiness and inexperience in manufacture.

After hearing the complaints of the contractor and certain of the steel manufacturers, the Board decided to abide by the requirements issued in accordance with the statutes, and for the fulfilment of which contracts had been made under bond, while making certain modifications in the system of tests in the direction of increased simplicity and efficiency. Accordingly, after many of these tests had been made without failure on the material delivered, the ring test was discontinued, and subsequently the close test of angles, which, being designed to detect reediness in the material, was considered unnecessary in connection with the open test. The inspector of shapes was also authorized to make the required tensile tests at Johnstown on each heat of steel, the flat pieces for test being so rolled as to have, as near as may be, the same work of reduction both of area and of thickness as in the finished shapes. The split tests for tees and deck-beams were omitted, since equivalent work was done on each end of deck-beams in forming the beam-arms in the shipyard, while, by agreement, an open and close test (see p. 176) for these shapes was substituted.

It had been urged that the arbitrary division of material into lots without regard to furnace run or heat might result in the acceptance of material not fulfilling the requirements for strength and ductility, while a failure of any lot to pass these tests would throw upon the manufacturer's hands a number of finished plates which could subsequently be disposed of only at a great loss. It was accordingly decided that a "lot of material" should consist of the total product of a furnace-heat without regard to the number of pieces, and the tensile tests be made from a plate rolled down from an ingot of the heat selected at random, the rest of the heat remaining in ingot form until acceptance under the tensile tests, in accordance with the following additional instructions:

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington City, October 6, 1883.

INSPECTOR OF MATERIAL:

It having been found that the arbitrary division of material into lots of twenty pieces each may lead to the accidental acceptance of material which is not up to the requirements of tensile strength and ductility, it is decided that hereafter a lot of material shall consist of all plates and angles or other pieces which are made from the same heat.

In testing a lot the conditions of acceptance will be as prescribed in the "Tests of Steel, &c.," except that instead of selecting from the finished metal a plate or bar for test, the inspector may, if the manufacturer prefer this method, select at random an ingot from a heat and have it, or rather a portion thereof, rolled into a plate or bar, from which test-pieces shall be cut, provided always that the same amount of mechanical work is done upon them in rolling as is done upon the average finished plate or bar of the same weight per square or lineal foot.

The instructions for testing in this manner shall read as follows:

IN CASES OF FAILURE.

If the average of these four test-pieces, numbered 1, 2, 3, 4 (called Test I.), fall below either of the required limits, the ingot from which pieces 1, 2, 3, 4 were cut shall be rejected, and Test II. made, consisting of pieces 5 and 6, cut from a second ingot or a portion thereof. If the mean of the results of these two fall below either of the above limits, the entire lot shall be rejected. If it be successful, Test III., or the mean of pieces 7 and 8, cut from a third ingot, shall decide.

If in any of Tests I., II., III., any single piece shows a tensile strength less than 58,000 pounds, or a final elongation less than 21 per cent., the ingot from which it was cut shall be rejected and that test considered to have failed regardless of its average.

The quenching and other tests must still be made upon the finished material as prescribed.

If the manufacturers see fit to communicate the results of chemical tests to the inspectors, the Board will be glad to receive the information.

Very respectfully,

R. W. SHUFELDT,
Rear-Admiral, U. S. N., President of the Board.

Having abandoned the arbitrary division of material into lots, the tests across the grain, being now only representative of the condition of the individual plate tested, were omitted. Inasmuch as the tensile tests so made were fairly representative of the whole heat of steel, the individual test was omitted for the boiler-plates, which were tested in the same manner as ship-plate, and with the original limits of tensile strength and ductility, but omitting the required average strength of 60,000 pounds.

While omission of certain tests may be looked upon as a concession to the manufacturers, made entirely to hasten delivery and not to be repeated, in the main the changes amount to a recasting of the method for increased simplicity, and, to a certain extent, increased efficiency, while diminishing the amount of labor previously involved.

No change was made in the prescribed tests for rivets, except that, upon the recommendation of the inspector, the pieces were riveted up in single shear instead of double shear, thereby increasing the representative value of these tests.

So amended, the system of tests was carried out on all material subsequently delivered, and the increasing success of the manufacturers in meeting the specifications demonstrated the wisdom of the Board's conclusions that the chief difficulties and delays were due to inexperience, while the almost complete absence of failures in working the material in the shipyard, though by workman previously inexperienced in the treatment of steel, gave evidence of its high quality.

In the early parts of the work some difficulty was experienced in rolling light plates and angles within the prescribed limits, so that it was deemed advisable to allow plates of $12\frac{1}{2}$ pounds per square foot and less to vary between 3 per cent. above and 5 per cent. below the specified weight, and that the limits should be the same for angles of 6 pounds per lineal foot and less. The effect of this was not so much to produce material heavier than the specified weight, but, in removing the tendency to roll this material too light, the actual weights were brought more

nearly to the specified weights, on account of the increased confidence of the rollers in removing the fear of the rejection of the material were it a trifle heavy. This is a desirable condition, for in bulkhead plates and the lighter angles it is more important that the strength and stiffness designed to should be obtained than that the weight of hull should be so slightly increased.

Butt-straps, required in the specifications to be cut in the shipyard, were also allowed to be sheared out at the mills, with due regard to the direction of the grain.

In the matter of annealed material, the test pieces for tensile and cold tests, while allowed to be removed before annealing, were required to be treated in all respects like the corresponding plates, being placed in the annealing furnace along with them.

Under these arrangements, the inspection and delivery of material proceeded very satisfactorily, with the exception of the trouble with the quenching test at the Black Diamond Works, the probable cause of which will be specially considered later on.

Under a separate heading the manufacture and results of the steel produced at each of the works are given as completely in detail as appears desirable for the purposes of a general report, and, as the greater part of the material had been delivered and worked into hulls and boilers by that time, the results are given up to September 1, 1884. The information as to production, together with the chemistry of charge and product, is, in each case, as supplied by the manufacturer.

CHESTER STEEL.

(Lieuts. F. P. Gilmore and G. A. Bicknell, U. S. N., Inspectors.)

The material to be supplied consisted of boiler and ship plate made and rolled at the Chester Rolling Mills, Thurlow, Pa. The steel was made by the Siemens-Martin, or "pig and scrap," process in two 15 ton furnaces, designed by Mr. C. M. Ryder and erected in 1882, with straight high roof and curved sand bottom, 18 feet long from port to port, with hearth 12 feet long, of increasing width from port to center. The general design and arrangements of the furnaces are excellent, and embody principles only more recently developed in Europe. Siemens producers are used, but slight changes were completed in April, 1884, in one of the furnaces, adapting it to the use of vapor fuel, which, however, has not been used except for a few heats not for the cruisers.

The charge consisted of about 12 tons of pig-iron, steel scrap, shearings, muck-bar, and charcoal-blooms, all charged cold in proportions based upon the indications of the tensile tests and varied from time to time.

As regards the production of this steel, Mr. P. G. Salom, chemist and superintendent of steel department, Chester Rolling Mills, in a paper before the American Institute of Mining Engineers (February, 1884), says:

The first hundred heats, from No. 464 to No. 563, in addition to the usual amount of pig-iron, scrap, and shearings, contained charcoal-blooms and muck bar (gradually increased amounts of muck-bar and a corresponding diminution of blooms, which were at first charged in equal amounts). Nos. 564 to 619 were all made from muck-bar, with results equally if not more satisfactory than with blooms. Of the remaining heats, a few were made from all blooms, a few from all muck-bar, and the others from a mixture of the two.

Manganese was added to the bath before tapping.

The ingots were bottom cast with central runner and base plate, the sizes in general use being 40 inches by 18 inches by 7 and 9 inches thick. Plates $\frac{3}{8}$ inch thick were rolled from previously rolled slabs reheated, while plates $\frac{1}{4}$ to $\frac{1}{2}$ inch thick were rolled direct from the ingot. Plates more than $\frac{1}{2}$ inch thick were rolled from ingots 10 by 24 by 60 inches and 10 by 35 by 60 inches, these two molds being considered special sizes.

It may be here observed that the thirteen reductions from a 10-inch ingot to the $\frac{3}{8}$ -inch plates of the Dolphin's boiler-shells and protective deck of Atlanta and Boston, or the ten reductions to the 1-inch protective deck plates of the Chicago, are less than generally considered necessary in such cases in Europe, and the attention of the manufacturers may have to be called to the desirability of using thicker ingots, unless some method can be devised for obtaining sounder ingots without carrying too high silicon. The defects of a plate which has received too little work may not in general be detected by a few tests, and are undoubtedly rendered more apparent in flanging and working.

The mills used are 80 and 100 inches long between housings, with rolls 32 inches in diameter, in continuous connection, and driven by a Corliss horizontal engine, with 32-inch cylinder and 6-foot stroke, using steam of 70 pounds gauge-pressure, and running at about 54 revolutions, with fly-wheel 30 feet in diameter, weighing about 50 tons.

The testing machine (Fig. 4) is one of the many patterns of triple-lever machines, made by Messrs. Riehlé Bros., of Philadelphia. The straining mechanism consists of upper (the fixed) wedge-block supported by standards carried by the main frame-work, with lower block moving in slides in these standards and carried by four leading-screws attached to the cross-head of a hydraulic plunger beneath the platform of the machine. Power is applied through a hydraulic cylinder and pump, either by hand or belt and gearing, the three oil-valves being connected 120° apart to the crank shaft, thus giving continuous motion to the lower wedge-block. The throw of the pump can also be altered to suit the nature of the work. There are primary and jockey-weight beam-arms, with adjustable compensating attachment, and connected with the straining mechanism by double levers. The primary scale is divided into increments of 2,000 pounds up to 100,000 pounds, while the jockey-weight scale is divided into intervals of 10 pounds each up to 2,000 pounds.

For flat pieces the Riehlé patent high-faced wedge (Fig. 5) is used, which, being thicker along the middle, retains the piece in line upon the first pressure being applied. For rounds double angle-faced wedges are provided. Most of the tensile tests of rivet bar were made on this machine.

The specimens for tensile tests were removed by shearing, straightened cold, and cut out in a planing machine, and were fairly well shaped. Measurements for sectional area were made near each witness-mark, and in the center of the piece, in order to obtain the least value in the part to be stretched and to avoid marked differences along the length. The measured length was laid off with Brown & Sharp's long-slide micrometer gauge fitted with fine points, the witness-marks being light punch-marks. The thickness for sectional area at fracture was measured midway between one edge and the center, but with a square-jawed sliding gauge. The result on the average is believed to be very nearly correct.

The quenching pieces were at first heated in a smith's forge with cold blast, but subsequently in a small furnace attached to the annealing

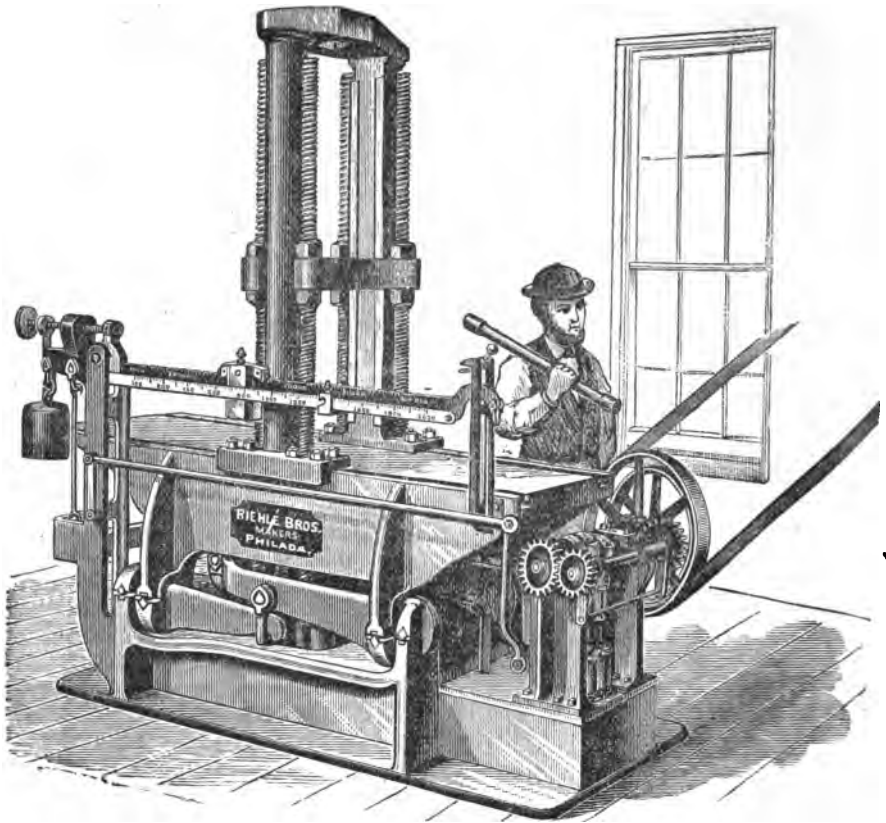


FIG. 4.—100,000 pounds Riehle Hydraulic Testing Machine used at Chester Rolling Mills.

DIMENSIONS.

Extreme height	8 ft. 3 in.
Extreme length	6 ft. 4 in.
Extreme width	3 ft. 6 in.

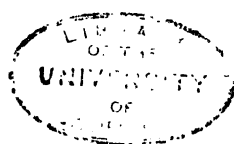
Weight, 7,225 lbs.

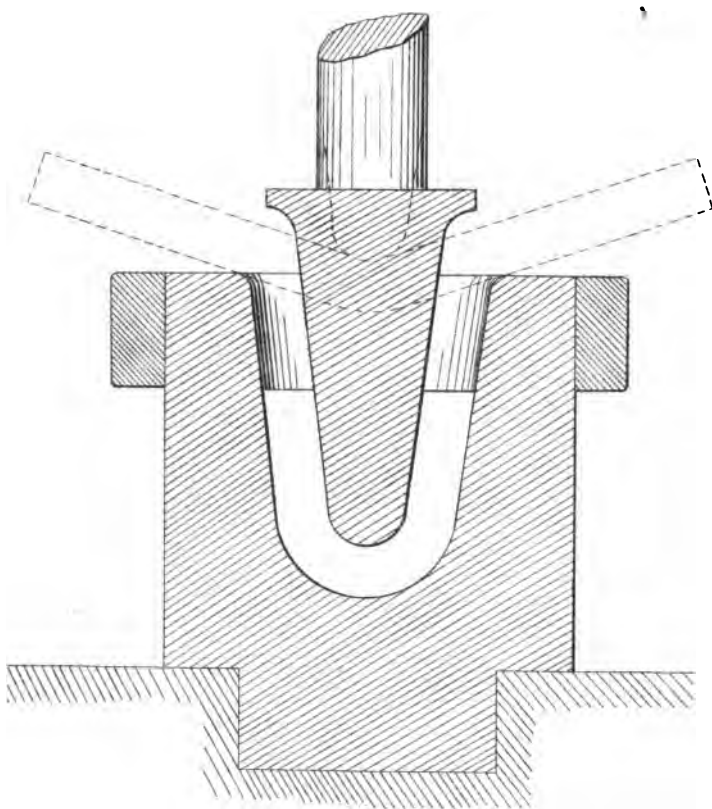
ADAPTATION.

Tensile specimens	10 in. to 4 ft. long.
Round "	2 in. diam. or less.
Square "	2 in. x 2 in. or less.
Flat "	3 in. or less x 1 in. or less.
Transverse specimens	12 in. to 5 ft. long.
" space	3 ft. 6 in. high x 11 in. wide.
Compressive specimens	3 ft. 6 in. long or less.
" surfaces	11 in. x 11 in.
Motion of plunger	12 in.



Fig. 5.—High Faced Wedge.





*Plate II.- Apparatus for Bending Quenching Test Pieces
at Chester Rolling Mills.*

furnace, and originally intended for annealing small pieces. A bridge 3 or 4 inches high, between the fire and the hearth, prevented the flame from playing on the pieces, and the furnace was never smoky except immediately after firing. The pieces were inserted as left curved by the shears. Lieutenant Gilmore reported a difference in the behavior of pieces under the quenching test according as they were heated in the annealing furnace or at the forge, in the latter case becoming hard to scratch with a file, and at times highly tempered, brittle, and hard to work.

After being cooled in water at 82° Fahr., they were bent smoothly in a form, as shown in Plate II., by hydraulic power, in an apparatus devised out of an old punching machine.

Sufficient chemical information accompanies the record of tests to enable the curve of carbon properties, p. 554, to be constructed, which shows graphically the average behavior of this steel under tensile test. Discussion of this curve is reserved until that of the other steels can be considered. Drillings for chemical test were taken from small test ingot, ladled from the furnace while tapping.

The chemical methods in use are—for combined carbon, the color test (p. 546, 547), dissolving a standard each time; for manganese, by dissolving in acid protosulphate of iron the binoxide precipitated from nitric-acid solution by chlorate of potash, and treating with permanganate of potash; for phosphorus, the molybdate of ammonia method, weighing the yellow precipitate of ammonia. The magnesia method was sometimes used for checking results.

The total number of heats tested to September 1, 1884, is 297, of which 60, or 20.2 per cent., were rejected on the tensile tests. In justice to the manufacturers, it should be stated that many of these rejected heats were made before the inspection was commenced, and it may be said here that nowhere throughout this report are any invidious comparisons intended of the relative success of different manufacturers in producing material to the specifications. Individual circumstances largely control appearances in such matters. Of the material so accepted 1,616.17 tons were delivered at the ship-yard up to September 1, 1884, while 14.73 tons, or 0.91 per cent., of the amount delivered, failed on the quenching test.

In the following tables the results are given in the order of heat-numbers, which was not the order of testing. This arrangement is, however, at once more convenient and better illustrates the increasing success in meeting the requirements.

For heats tested with and across the grain the separate tests are given as reported; for the others the tests with the grain are averaged.

TABLE IV.—Tensile tests, Chester steel.

[SYMBOLS.—A., accepted; R., rejected; F., failed; S., ship quality; B., boiler quality; — in the direction of rolling; + across the direction of rolling.]

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Per ct.	Per ct.	Per ct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
329				.990	.7350	.7276	54,100	28.00	33.00	1	R.
342				.985	.7180	.7060	53,800	29.70	31.40	1	R.
345				.990	.7000	.6930	51,600	30.46	44.20	1	R.
350				1.125	.4775	.5294	54,835	25.78	43.50	4	R.*
380				1.180	.5615	.6626	62,100	28.30	47.00	2	A. S.
383				1.280	.4550	.5642	64,450	27.35	49.50	2	A. S.
398				.960	.6800	.6328	55,100	28.06	33.00	1	R.
412				.993	.6740	.6692	59,750	27.97	39.70	2	A. B.
413				1.237	.5000	.6285	60,650	25.53	47.35	2	A. S.
416				1.248	.6175	.7703	60,000	29.10	42.75	2	A. S. B.
417				.993	.5910	.5869	58,250	28.70	41.00	2	A. B.
427				1.030	.6860	.7006	54,700	29.45	33.30	1	R.
435				.963	.7120	.6856	56,800	27.81	37.80	1	R.
437				1.003	.5800	.5817	67,132	23.13	52.20	1	R.
439				1.000	.5740	.5740	62,000	20.16	58.00	1	R.
440				1.000	.7030	.7030	60,527	27.13	41.20	2	A. S. B.
440				1.082	.4910	.5555	66,850	25.00	48.95	2	R.
442				1.021	.5060	.5168	54,050	29.40	40.00	2	R.
443				.998	.5060	.5020	56,670	28.20	41.00	1	R.
444				1.270	.5410	.6953	58,500	27.63	47.75	2	A. B.
446				1.133	.4375	.4957	59,725	25.16	46.85	2	A. B.
451				.990	.8160	.8078	56,500	31.10	35.40	1	R.
456				.995	.4570	.4547	58,500	25.38	39.00	1	R.
462				.974	.4600	.4480	65,550	26.80	45.35	2	A. S.
461				.948	.6750	.6296	61,483	26.19	48.60	2	A. S. B.
462				.956	.6725	.6294	57,060	27.99	42.60	2	A. B.
463				1.204	.4830	.5615	66,890	24.50	50.00	1	R.†
464				1.217	.4850	.5602	63,876	20.30	53.70	1	F.
464				1.244	.4550	.5622	70,800	24.00	53.70	1	F.
464	.19	.37	.039	1.240	.4550	.5642	70,900	19.70	54.20	1	F.
464	.19	.37	.039	.967	.7070	.6837	66,978	25.41	48.50	4	A. S.;
465	.13	.38	.035	1.245	.4820	.6000	61,000	28.20	42.00	1	A. S. B.
465	.13	.38	.035	1.250	.4820	.6025	59,580	24.72	47.00	1	A. S. B.
467				.984	.5790	.5697	69,000	27.82	53.00	1	A. S.
467				.972	.5910	.5745	67,467	21.43	55.10	1	A. S.
469				.975	.4480	.4368	62,900	26.50	45.00	1	A. S. B.
469				1.264	.6000	.7584	61,313	25.32	48.00	1	A. S. B.
470				1.250	.5900	.7375	62,047	27.28	45.00	1	A. S. B.
470				1.250	.5950	.7437	62,570	23.44	47.00	1	A. S. B.
472				1.000	.4600	.4600	60,130	27.12	42.00	1	A. B.
472				1.000	.4630	.4630	59,600	24.27	50.00	1	A. B.
473				1.168	.4940	.5693	59,400	28.14	41.35	2	A. B.
475				1.062	.4507	.4733	57,640	28.63	42.50	3	A. B.
477				1.248	.4410	.5504	58,150	28.75	47.45	2	A. B.
478				1.000	.6150	.6150	55,600	30.10	41.50	1	R.
479				.999	.5290	.5284	55,400	26.60	39.00	1	R.
480				1.028	.5600	.5756	59,000	29.68	43.70	1	R.‡
480				1.000	.5640	.5640	57,400	28.61	52.70	1	R.
481	.11	.36		1.000	.4750	.4750	55,000	24.05	45.00	1	R.
482	.20	.38		1.660	.4950	.6266	63,826	26.70	48.50	1	A. S.
482	.20	.38		1.660	.5040	.6380	64,500	21.00	57.00	1	R.
483	.11	.36		1.255	.4850	.5941	55,200	27.60	41.30	1	R.
484	.21	.40		1.205	.4180	.5036	71,000	23.52	54.20	1	R.
484	.21	.40		1.254	.4100	.5517	70,860	21.10	62.60	1	R.
485	.11	.34		1.250	.5070	.6367	55,200	28.40	39.80	1	R.
486	.12	.37		1.135	.5000	.5675	63,665	28.43	48.20	1	A. S. B.
486	.12	.37		1.240	.5730	.6361	61,400	22.45	57.40	1	A. S. B.
477	.15	.37		1.190	.5750	.6842	60,140	27.13	40.75	1	A. S. B.
487	.15	.37		1.249	.5860	.7219	60,050	26.05	46.50	1	A. S. B.
489	.13	.40		1.246	.4810	.5993	59,240	25.31	42.10	1	R.‡
489	.13	.40		1.253	.4730	.5926	57,880	32.18	52.50	1	R.‡
490	.21	.56		1.287	.3390	.4023	73,500	20.75	46.00	1	R.
491	.17	.50		1.260	.4080	.5140	64,000	25.20	60.00	1	A. S.
491	.17	.50		1.262	.4110	.5186	63,000	25.58	48.20	1	A. S.

* Final area for 3 tests only.

† Two annealed plates accepted. See Annealing, p. 526.

‡ Retest allowed.

§ Would have been accepted for boiler metal when requirement of 60,000 pounds average tensile strength was waived.

|| Subsequently accepted for boilers, and five plates shipped.

TABLE IV.—Tensile tests, Chester steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Perct.	Perct.	Perct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
492	.13	.49		1.256	.2920	.3677	64,310	25.00	55.00	1	A. S.
492	.13	.49		1.265	.2930	.3706	63,800	28.30	48.10	1	A. S.
493	.16	.53		1.260	.5090	.6413	68,600	24.78	55.00	1	F.*
493	.16	.53		1.254	.3610	.4527	66,200	25.31	45.40	1	A. S.†
493	.16	.53		1.250	.3670	.4587	65,600	25.06	46.80	1	A. S.
494	.16	.50		1.234	.3885	.4792	65,900	24.92	46.55	1	A. S. B.
495	.13	.49	.062	1.250	.3120	.4275	61,500	24.62	45.30	1	A. S.
495	.13	.49	.062	1.265	.3440	.4351	59,700	25.56	53.60	1	A. S. B.
497	.13	.46		1.254	.2990	.3701	62,900	24.50	46.00	1	A. S.
497	.13	.46		1.250	.3154	.3937	61,700	23.14	50.70	1	F.†
498	.16	.49	.058	1.250	.2690	.3362	71,555	19.75	54.25	1	A. S.†
498	.16	.49	.058	1.113	.4730	.5286	64,450	24.71	46.55	1	A. S.
499	.15	.50	.031	1.243	.3853	.4782	64,850	24.65	47.50	1	A. S.
500	.15	.49		1.125	.3890	.4238	64,685	25.15	47.27	1	A. S.
501	.14	.56		1.038	.3865	.4154	65,893	24.14	48.72	1	A. S.
502	.15	.50		1.111	.4220	.4622	62,845	25.40	45.75	1	A. S. B.
503	.17	.58		1.120	.4430	.4946	72,500	23.85	58.10	1	A. S.
504	.17	.58		1.000	.4840	.4837	64,200	24.90	47.55	1	A. S.
505	.15	.39		.985	.4575	.4506	61,700	27.55	42.90	1	A. S. B.
506	.14	.43		.977	.4850	.4738	62,125	26.65	40.90	1	A. S. B.
507	.15	.54		1.205	.4290	.5166	65,800	24.80	50.00	1	A. S.
508	.14	.49		1.250	.4750	.5938	62,550	26.80	49.10	1	A. S. B.
509	.12	.53		1.250	.4580	.5725	62,350	26.30	47.10	1	A. S. B.
510	.15	.47		1.248	.4640	.5788	61,895	25.80	44.50	1	A. S. B.
511	.15	.48		1.000	.4725	.4725	61,150	26.55	46.95	1	A. S. B.
512	.16	.48		1.000	.4870	.4870	64,450	24.55	46.20	1	A. S.
513	.14	.47		.986	.4620	.4555	60,900	26.20	44.40	1	A. S. B.
514	.15	.40		.983	.4425	.4350	63,350	23.48	44.35	1	A. S.
515	.16	.53		1.236	.3825	.4728	68,100	24.65	51.70	1	A. S.
516	.16	.43		1.229	.4775	.5863	63,500	26.62	43.85	1	A. S.
517	.22	.43		1.247	.4480	.5584	66,075	23.74	48.00	1	A. S.
518	.19	.43		1.252	.4040	.5058	67,100	25.00	43.65	1	A. S.
519	.18	.49		.968	.4375	.4235	64,950	25.14	48.30	1	A. S.
520	.15	.46		.977	.6875	.6717	62,100	25.60	50.40	1	A. S. B.
521	.14	.44		.975	.5910	.5745	63,850	27.05	44.95	1	A. S.
522	.16	.46		.983	.6870	.6753	66,700	23.75	48.85	1	A. S.
523	.14	.38		.996	.7090	.7061	61,640	27.43	43.90	1	A. S. B.
524	.14	.39		.988	.7095	.7006	61,100	26.60	47.35	1	A. S. B.
525	.16	.46		1.245	.5290	.6586	66,450	21.77	56.35	1	R.
526	.14	.46		.965	.7015	.6769	60,370	24.73	48.25	1	A. S.
527	.14	.41		.976	.7055	.6886	63,285	24.05	50.45	1	A. S.
528	.21	.46		.993	.7085	.7036	74,535	24.30	50.50	1	A. S.
529	.16	.40		.992	.6975	.6916	62,425	25.60	48.75	1	A. S. B.
530	.18	.43		.983	.7015	.6892	69,650	23.13	47.80	1	A. S.
531	.16	.35		.997	.5760	.5740	65,745	25.07	50.80	1	A. S.
532	.17	.35		.982	.5545	.5442	70,570	23.90	52.30	1	A. S.
533	.14	.30		.979	.8350	.8070	58,815	28.00	42.25	1	A. B.
534	.12	.25		.975	.7170	.6987	57,275	28.40	40.50	1	A. B.
536	.11	.45		.908	.6965	.6319	54,100	28.64	42.50	1	R.
537	.11	.36		1.248	.3715	.4636	60,510	26.80	42.75	1	A. S. B.
538	.11	.24		1.156	.4950	.5726	56,250	29.90	37.85	1	R.
539	.14	.33		1.127	.4835	.5456	57,730	27.45	41.55	1	A. B.
540	.10	.31		1.281	.3580	.4586	62,050	24.62	50.05	1	A. S.
541	.13	.29		1.230	.3445	.4237	60,275	25.05	44.25	1	A. S. B.
542	.14	.36		1.230	.3725	.4581	60,410	27.98	49.35	1	A. S. B.
543	.15	.31		1.230	.4130	.5080	57,190	29.73	40.55	1	A. B.
544	.14	.27		1.210	.4630	.5602	54,800	30.00	43.30	1	R.
545	.13	.32	.061	1.261	.3350	.4224	54,600	28.30	44.00	1	R.
546	.14	.29	.057	1.267	.3990	.5055	58,300	27.20	44.60	1	A. B.
547	.15	.30	.058	1.259	.4300	.5413	57,450	30.85	38.50	1	A. B.
548	.16	.27	.069	1.251	.3535	.4420	59,150	29.30	40.95	1	A. B.
549	.19	.34	.069	1.118	.4440	.4914	63,300	27.70	43.50	1	A. S.
550	.15	.40	.064	1.258	.3325	.4131	63,885	28.47	45.95	1	A. S.
551	.11	.28	.075	1.250	.4320	.5400	54,900	31.25	39.10	1	R.
552	.13	.30	.075	1.157	.4125	.4770	57,750	28.64	43.75	1	A. B.
553	.11	.25	.051	1.155	.3715	.4225	52,185	30.05	37.30	1	R.
554	.16	.42	.062	1.040	.4160	.4409	60,400	28.10	43.50	1	A. S. B.
555	.14	.28	.064	1.090	.4055	.4414	59,000	28.63	43.45	1	A. B.
556	.15	.30	.043	.762	.6910	.5264	58,603	29.10	43.65	1	A. B.
557	.14	.29	.050	1.281	.3650	.4677	57,090	27.72	44.65	1	A. B.

* Quenching test failed.

† A second plate.

‡ Probably finished too cold.

TABLE IV.—*Tensile tests, Chester steel—Continued.*

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	No. of tests.	Accepted or rejected.
	Per cent.	Per cent.	Per cent.	Inches.	Inches.	Sq. ins.	Pounds.	Per cent.	Per cent.		
558	.15	.38	.046	1.255	.3800	.4770	63,100	23.67	51.85	2	A. S.
559	.16	.27	.052	1.023	.3465	.3543	57,850	28.80	40.15	2	A. B.
560	.11	.30	.052	1.023	.3240	.3314	56,400	29.06	40.00	1	R.
561	.16	.39	.039	1.030	.4835	.4980	60,490	26.12	48.05	2	A. S. B.
562	.16	.28	.050	.990	.4725	.4678	57,750	29.05	41.55	2	A. B.
563	.14	.33	.044	.994	.4610	.4582	57,630	29.30	41.85	2	A. B.
564	.16	.40	.037	1.311	.3505	.4595	58,500	25.25	41.50	2	A. B.
565	.18	.39	.038	.990	.5390	.5336	60,545	28.45	43.55	2	A. S. B.
566	.20	.41	.039	.980	.5275	.5169	59,000	29.27	41.85	2	A. B.
567	.17	.27	.050	1.021	.5335	.5447	58,545	29.45	39.50	2	A. B.
568	.17	.42	.044	1.026	.4975	.5102	61,900	27.72	45.80	2	A. S. B.
569	.17	.44	.042	1.026	.3590	.3683	66,200	23.04	56.50	2	A. S.
570	.17	.42		1.019	.3725	.3795	63,600	29.62	46.40	2	A. S.
571	.16	.41	.047	1.028	.5945	.6111	62,900	23.84	55.60	2	A. S.
572	.15	.37	.053	1.032	.5650	.5831	57,570	29.68	46.75	2	A. B.
573	.17	.29	.039	1.042	.7000	.7290	59,400	26.74	53.40	2	A. B.
574	.14	.35	.038	1.037	.7010	.7267	57,100	28.70	41.60	2	A. B.
575	.13	.30	.042	.828	.5685	.4704	59,350	26.55	40.85	2	A. B.
576	.14	.36	.048	.993	.5650	.5552	61,300	26.95	41.10	2	A. S. B.
577	.14	.39	.033	.970	.5500	.5335	57,050	30.45	39.00	2	A. B.
578	.14	.40	.050	.917	.5535	.5074	57,880	30.25	38.55	2	A. B.
579	.15	.37	.047	.794	.5405	.4339	60,100	26.95	41.45	2	A. S. B.
580	.17	.41	.042	.882	.7095	.6255	60,215	25.01	41.95	2	A. S. B.
581	.14	.33	.047	1.110	.7080	.7856	58,550	29.87	42.75	2	A. B.
582	.15	.36	.048	1.098	.5725	.6283	57,850	30.84	48.50	2	A. B.
583	.15	.32	.055	1.265	.5490	.6945	57,215	31.45	46.40	2	A. B.
584				1.258	.4735	.5954	78,100	22.61	58.00	2	R.
585				1.252	.4665	.5445	66,050	26.30	45.85	2	A. S.
586	.13	.33	.052	1.248	.4725	.5894	58,610	26.10	46.40	2	A. B.
587	.14	.33	.046	1.244	.4725	.5880	60,900	27.90	49.50	2	A. S. B.
588	.16	.43	.048	1.247	.4990	.6223	61,600	25.15	43.15	2	A. S. B.
589	.16	.49	.046	1.305	.4730	.6173	64,850	24.75	48.15	2	A. S.
590	.14	.39	.052	1.220	.4835	.5898	62,700	25.75	46.50	2	A. S. B.
591		.46	.09	1.242	.4890	.6071	64,650	25.96	50.85	2	A. S.
592	.14	.41	.041	1.228	.5185	.6367	65,590	25.30	57.55	2	A. S.
593	.19	.44	.034	1.290	.5040	.6449	62,500	25.65	51.50	2	A. S. B.
594	.15	.42	.052	1.275	.4920	.6221	62,550	27.58	50.90	2	A. S. B.
595	.13	.36	.046	1.260	.4465	.5626	58,750	27.25	45.30	2	A. B.
598	.12	.34	.054	1.234	.5015	.6186	56,550	27.65	42.35	2	R.
599				1.218	.5075	.6183	32,500			2	R.*
600	.18	.40	.060	1.242	.5015	.6229	65,950	22.10	51.10	2	R.
601	.18	.37	.048	1.224	.4825	.5903	64,750	25.25	52.80	2	A. S.
603	.19	.73	.056	1.256	.4945	.6216	69,700	21.50	61.85	2	R†
605	.17	.50	.044	1.185	.4390	.5202	64,600	24.45	60.60	2	A. S.
606	.14	.47	.042	1.175	.5090	.5980	65,000	19.70	60.00	1	R.
607	.15	.29	.048	.953	.7058	.6721	65,350	24.08	53.92	4	A. S.
608	.16	.27	.043	1.209	.5090	.6152	60,050	25.20	46.00	2	A. S. B.
609	.15	.29	.052	1.237	.5095	.6303	63,250	23.22	53.30	4	A. S.
610	.15	.38	.062	1.219	.4745	.5784	64,950	27.05	48.50	2	A. S.
611	.17	.38	.047	1.212	.4735	.5747	64,850	25.56	53.65	2	A. S.
612	.16	.32	.065	1.238	.4815	.5903	62,500	23.54	52.77	4	A. S.
613	.16	.39	.061	1.245	.4565	.5681	62,950	23.75	54.50	2	A. S.
614	.16	.39	.051	1.240	.4590	.5692	61,000	27.55	51.10	2	A. S. B.
615	.17	.41	.051	1.244	.4715	.5866	62,350	26.15	50.25	2	A. S. B.
616	.16	.41	.057	1.264	.5000	.6320	62,050	26.60	47.50	2	A. S. B.
618	.15	.45	.057	1.260	.5130	.6464	67,050	23.25	58.70	2	A. S.
619	.16	.36	.059	1.263	.5300	.6947	63,050	26.05	62.00	2	A. S.
620				1.254	.4985	.6249	73,000	23.30	55.30	2	A. S.
621	.15	.36	.048	1.247	.5423	.6763	62,750	24.85	48.80	2	A. S.
622	.17	.47	.051	1.250	.5395	.6744	63,350	26.57	51.25	2	A. S.
623	.15	.43	.060	1.246	.4835	.6023	63,300	26.75	52.60	2	A. S.
624	.15	.41	.052	1.249	.4860	.6066	68,200	27.44	62.05	2	A. S.
625	.16	.38	.061	1.260	.4605	.5879	60,300	25.90	51.25	2	A. S.
626	.19	.33	.045	1.258	.4650	.5849	68,070	23.10	63.22	4	A. S.
627	.19	.41	.050	1.250	.5110	.6388	71,700	25.20	56.45	2	A. S.
628	.12	.36	.053	1.250	.4940	.6175	58,000	26.40	48.70	2	A. B.
629				1.218	.5200	.6176	61,700	25.50	51.50	2	A. S.
630	.13	.49	.048	1.176	.5218	.6158	60,720	23.15	52.65	2	A. S.
631	.17	.44	.051	1.225	.4905	.5991	63,550	23.46	56.65	2	A. S.
632	.14	.34	.052	1.194	.4745	.5663	63,000	26.10	52.00	2	A. S.
633	.15	.41	.047	1.207	.4950	.5975	58,600	25.65	45.75	2	A. B.

* Broke in grips; cryst. fract.

† Fracture laminated.

TABLE IV.—Tensile tests, Chester steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	No. of tests.	Accepted or rejected.
	Pr. ct.	Pr. ct.	Pr. ct.	Inches.	Inches.	Sq. ins.	Lbs.	Per ct.	Per ct.		
634	.10	.45	.051	1.233	.5000	.6163	61,650	25.00	50.55	2	A. S.
635	.13	.36	.056	1.206	.4875	.5879	57,230	26.20	47.75	2	A. B.
636	.15	.30	.051	1.199	.4825	.5785	59,350	23.47	50.50	2	R.
637	.13	.31	.049	1.198	.4810	.5762	52,750	27.75	46.75	2	R.
638	.14	.39	.049	1.255	.5305	.6655	66,150	23.75	57.70	2	A. S.
639	.13	.36	.050	1.248	.5230	.6524	57,440	26.80	48.50	2	A. B.
640	.13	.30	.049	1.258	.4900	.6162	59,000	24.05	49.60	2	A. B.
641	.14	.42	.054	1.277	.4950	.6321	63,200	25.45	52.85	2	A. S.
642	.12	.24	.047	1.273	.4915	.6254	56,900	27.30	45.55	2	R.
643	.15	.30	.040	1.284	.4850	.6225	61,100	28.40	47.75	2	A. S. B.
644	.15	.41	.055	1.263	.4990	.6268	60,600	26.55	50.80	2	A. S. B.
645	.13	.33	.061	1.234	.5045	.6223	58,150	27.85	51.00	2	A. B.
646	.15	.33	.050	1.243	.4985	.6196	59,300	26.15	52.00	2	A. B.
647	.12	.38	.048	1.243	.4540	.5641	58,850	26.25	50.25	2	A. B.
650	.14	.34	.042	1.225	.5205	.6375	61,750	24.35	51.90	2	A. B.
652	.16	.31	.059	1.216	.4945	.6010	64,200	26.30	52.00	2	A. S.
659	.16	.29		1.242	.5130	.6371	61,915	27.45	48.00	2	A. S. B.
660	.16	.31		1.236	.4890	.6044	66,500	19.95	59.00	2	R.
660	.16	.31		1.182	.5293	.6256	63,617	24.57	49.67	2	(*)
661	.12	.27		1.199	.4925	.5768	67,250	23.35	56.00	2	A. S.
662	.12	.27		1.196	.4900	.5725	60,850	27.75	41.00	2	A. S. B.
663	.12	.33		1.180	.4925	.5811	62,800	29.40	44.00	2	A. S. B.
664	.13	.32		1.194	.5000	.5968	63,800	24.85	46.05	2	A. S.
665	.16	.38		1.200	.5165	.6356	67,200	27.50	50.65	2	A. S.
666	.15	.37		1.217	.5125	.6031	61,750	25.50	48.15	2	A. S. B.
667	.13	.33		1.238	.5150	.6374	60,750	24.45	48.60	2	A. S.
668	.17	.34		1.227	.5100	.6255	67,000	23.95	50.65	2	A. S.
669	.17	.36		1.220	.5185	.6326	65,150	24.75	48.10	2	A. S.
670	.12	.31		1.215	.4850	.5892	60,490	26.25	45.75	2	A. S. B.
671	.13	.31		1.207	.4820	.5815	62,000	27.95	44.50	2	A. S. B.
672	.15	.37		1.097	.5865	.5863	61,200	26.75	43.75	2	A. S. B.
673	.14	.35		1.091	.4950	.5398	60,450	30.25	41.00	2	A. S. B.
674	.13	.29		1.226	.4870	.5970	62,075	28.40	41.00	2	A. S. B.
675	.11	.29		1.227	.5500	.6754	59,700	29.65	40.50	2	A. B.
676	.14	.30		1.240	.5075	.6294	60,800	26.05	43.00	2	A. S. B.
677	.15	.34		1.239	.5185	.6424	62,300	27.25	44.25	2	A. S. B.
678	.13	.32		1.227	.4935	.6055	60,200	30.30	43.75	2	A. S. B.
679	.14	.35		1.227	.5365	.6545	63,200	27.50	46.13	2	A. S.
680	.16	.29		1.236	.4995	.6774	65,450	28.70	47.00	2	A. S.
681	.14	.34		1.238	.5195	.6428	62,650	29.25	44.00	2	A. S. B.
682	.14	.34	.983	.983	.5045	.5005	56,600	26.15	42.15	2	R.
683	.13	.29	.976	.976	.4915	.4802	57,050	25.45	44.70	2	A. B.
686	.12	.24		1.018	.5050	.5408	54,450	27.50	40.45	2	R.
687	.12	.30		1.080	.4825	.5018	55,350	27.25	42.65	2	R.
688	.12	.28		1.096	.4980	.5458	54,915	29.30	42.70	2	R.
689	.12	.32		1.069	.5120	.5468	57,500	28.95	48.00	2	A. B.
690	.12	.38		1.082	.4920	.5326	57,350	26.65	42.25	2	A. B.
691	.15	.37		1.137	.5470	.6217	59,340	24.80	46.35	2	R.
692	.14	.35		1.163	.4860	.5688	60,250	29.15	45.60	2	A. S. B.
693	.16	.39		1.155	.5035	.5816	60,850	24.70	51.10	2	A. S.
694	.15	.40		1.130	.5025	.5678	60,100	25.90	53.55	2	A. S. B.
695	.14	.36		1.134	.5000	.5670	58,750	25.00	51.15	2	A. B.
696	.15	.44		1.035	.5150	.5331	60,480	25.35	48.70	2	A. S. B.
697	.14	.37		1.067	.4820	.5140	58,070	25.65	46.00	2	A. B.
698	.14	.35		1.147	.5075	.5562	57,750	26.55	49.50	2	A. B.
699	.15	.36		1.124	.5155	.5794	62,755	25.95	53.50	2	A. S. B.
700	.16	.37		1.090	.5890	.6420	60,170	24.15	47.80	4	A. S.
701	.16	.44		1.075	.5010	.5518	63,250	25.40	52.50	2	A. S.
702	.16	.44		1.023	.4895	.5005	61,585	24.20	47.10	2	A. S.
703	.14	.42		1.042	.4820	.5020	60,505	26.35	48.50	2	A. S. B.
704	.16	.48		1.033	.4790	.4946	63,500	26.25	49.55	2	A. S.
705	.16	.40		1.143	.5325	.5991	61,665	25.35	49.35	2	A. S. B.
706	.16	.39		1.025	.5365	.5496	60,315	25.15	47.83	2	A. S. B.
707	.15	.41		1.043	.5450	.5680	58,075	28.70	42.00	2	A. B.
708	.16	.39		1.056	.5300	.5597	61,795	26.10	45.00	2	A. S. B.
709	.16	.45		1.101	.4780	.4784	60,325	26.90	48.10	2	A. S. B.
710	.15	.35		.961	.5175	.4971	61,135	25.20	46.00	2	A. S. B.
711	.15	.40		1.317	.4875	.6418	60,365	23.75	50.90	2	A. S.
712	.15	.37		1.353	.5000	.6763	57,550	24.85	44.70	2	R.
713	.16	.38		1.005	.5000	.5025	61,100	23.80	45.40	2	A. S.
714	.16	.39		1.087	.5083	.5521	59,225	26.55	48.00	4	R.†
715	.14	.34		1.029	.5050	.5196	58,400	24.35	41.50	2	A. B.
716	.17	.41		1.029	.5150	.5297	62,250	25.55	48.00	2	A. S. B.

* Annealed. Test plate only accepted.

† Two pieces gave less than 57,000 pounds.

TABLE IV.—*Tensile tests, Chester steel.*—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	No. of tests.	Accepted or rejected.
	Perct.	Perct.	Perct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
717	.17	.46	.....	1.160	.5195	6.23	62,050	24.35	49.50	2	A. S.
718	.16	.28	.....	1.128	.4875	.5497	61,500	23.00	48.00	2	A. S.*
719	.16	.35	.....	1.106	.5155	.5702	60,850	24.50	54.70	2	A. S.
720	.16	.43	.....	1.094	.5135	.5618	61,000	23.44	44.50	2	A. S.
721	.17	.40	.....	1.022	.5100	.5210	60,500	25.30	51.00	2	A. S. B.†
722	.15	.44	.....	1.015	.5105	.5185	60,250	25.40	47.50	2	A. S. B.
723	.17	.47	.....	.998	.5050	.5038	60,300	24.60	48.50	2	A. S.
724	.17	.46	.....	.995	.5163	.5139	61,750	23.50	45.62	2	A. S.
725	.13	.22	.....	1.224	.5325	.6518	55,200	28.70	43.50	2	R.
726	.12	.22	.....	1.222	.5275	.6440	56,200	26.35	42.00	2	R.
727	.11	.41	.....	.990	.4770	.4722	63,000	21.20	48.00	2	R.
728	.16	.42	.....	1.027	.5030	.5213	62,250	19.20	48.00	2	R.
729	.13	.30	.....	1.020	.5110	.5212	60,850	23.40	45.00	2	A. S.
730	.14	.20	.....	1.015	.5135	.5183	62,000	23.65	41.00	2	A. S.
731	.13	.38	.....	.990	.5075	.5065	62,850	21.95	49.00	2	A. S.
732	.14	.38	.....	1.032	.5188	.5350	61,350	23.20	50.00	2	A. S.
733	.15	.48	.....	1.048	.5200	.5497	63,850	22.90	47.00	2	A. S.
734	.16	.....	.....	1.013	.5425	.5467	62,850	24.10	47.00	2	A. S.
735	.16	.40	.....	.993	.4960	.4925	65,000	26.00	41.50	2	A. S.
736	.15	.41	.....	1.125	.5275	.5910	61,750	24.30	42.00	2	A. S.
737	.15	.40	.....	1.110	.5250	.5830	62,000	25.10	45.00	2	A. S. B.
738	.15	.48	.....	1.055	.5188	.5485	64,375	22.58	47.25	4	R.
739	.15	.40	.....	1.080	.5450	.5890	62,400	24.00	40.00	2	A. S.
740	.15	.39	.....	1.080	.5250	.5670	63,400	25.05	41.00	2	A. S.
741	.15	.41	.....	1.098	.5125	.5620	62,500	25.35	42.00	2	A. S. B.
742	.12	.42	.....	1.023	.5225	.5340	61,200	24.85	44.00	2	A. S.
743	.14	.45	.....	1.026	.5063	.5195	61,075	22.63	43.00	4	R.
744	.12	.39	.....	.978	.5275	.5160	59,050	22.35	45.00	2	R.
745	.12	.36	.....	1.050	.4545	.4770	61,100	23.40	45.00	2	A. S.
746	.15	.41	.....	.968	.5415	.5240	63,500	19.95	55.00	2	R.
747	.15	.26	.....	.943	.5000	.4720	63,300	24.45	47.00	2	A. S.
748	.15	.40	.....	1.027	.5030	.5165	63,925	22.58	45.00	4	R.
749	.13	.41	.....	1.050	.4900	.5150	62,500	25.90	43.00	2	A. S. B.
750	.13	.33	.....	1.043	.4880	.5090	64,200	20.65	50.50	2	R.
751	.14	.39	.....	.899	.4933	.4435	63,425	22.83	46.75	4	R.
753	.14	.41	.....	1.038	.5025	.5210	61,100	23.25	46.50	2	A. S.
754	.14	.39	.....	1.038	.4925	.5110	62,000	24.60	47.50	2	A. S.
755	.14	.40	.....	.955	.5100	.4875	60,500	24.15	45.00	2	A. S.
756	.13	.26	.....	.939	.5135	.4825	57,650	24.45	40.00	2	R.
757	.13	.31	.....	.980	.5025	.4925	58,650	23.70	41.00	2	R.
758	.12	.27	.....	.983	.4980	.4895	58,850	24.65	41.00	2	R.
759	.13	.31	.....	.970	.5565	.5395	61,480	23.05	48.00	2	A. S.
767	.14	.45	.....	.982	.4950	.4860	60,700	25.25	50.50	2	A. S. B.

* Rough surface.

† One piece had rough surface.

NORWAY STEEL.

(Inspector, Lieutenant F. J. Drake, U. S. N.)

The material to be supplied consisted of ship and boiler plate. The steel was made at the Norway Steel and Iron Works, South Boston, and rolled into slabs, as hereafter described, being reheated and rolled into plate at the Bay State Iron Works, about a mile and a half distant.

At the end of 1883, the firm of Naylor & Co., previously controlling the Norway Works, was dissolved, and the works passed into the hands of a stock company, known as the Norway Steel and Iron Company, with a change of officers and foremen. Beyond the time consumed in overhauling the furnaces no delay was caused, the new company continuing the contracts. The drop in the heat-numbers in the table of tests was due to this change of management.

The steel was produced by the Siemens-Martin, or "pig and scrap" process, in three 10-ton furnaces, erected in 1873, and of the following inside dimensions:

	Ft.	In.
Width, in plane of ports	13	0
Depth, front to back ports	7	3
Height, crown to bed-floor	4	4

Gas is supplied to each furnace by a group of four Siemens producers, arranged in a rectangle, with central shaft, and each group supplied with steam-blast from an independent boiler.

From Heat No. 1892 to No. 2411, inclusive, the charge consisted usually of about one-eighth preheated Lonsdale pig, one-half puddle balls, and three-eighths shearings and pit-* and wrought iron scrap.

From Heat No. 39, and subsequently, the composition was variable.

The average weight of charge was 18,000 pounds.

Ferro-manganese was added to the bath about seven minutes before tapping; up to Heat No. 2411 from 130 to 160 pounds, subsequently 250 to 300 pounds.

The average time of a heat from charging to tapping was between five and a half and six hours.

Until June 14, 1884, including all heats between No. 1892 and No. 526, all ingots were top cast. Thence to August 1, some were top and some bottom cast, and subsequently, including all heats after No. 658, the bottom cast was alone used.

The molds in general use measured: inside, top 12 by 20½ inches; bottom, 13 by 21½ inches; depth, 60 inches, corresponding to a capacity of about 4,370 pounds. The ingots were stripped at a cherry heat, wash heated, and bloomed down to slabs from 4 to 7 inches thick and 21 inches wide, in a three high mill with collared rolls 58 by 30 inches, driven by a vertical condensing Corliss engine, 42 by 42 inches, of about 400 I. H. P., and using steam of 70 pounds, gauge pressure. These slabs are cut to length as required and sent to the Bay State Mills.

It will be observed that the average thickness of the ingots, 12½ inches, gives 25 per cent. more reduction than at the Chester Mills, which is better practice, though much depends on the conditions of casting.

Other molds, 8 by 26 by 60 inches and 10 by 26 by 60 inches, are occasionally used, and the corresponding ingots rolled down without blooming.

Throughout the supply of material under this inspection the upper third of the ingot was generally discarded on account of the unsatisfactory results obtained by special experiment on the corresponding rolled plate as described, p. 166, *et seq.*

At the Bay State Mills, the plate train is two-high, 110 by 30 inches, while a three-high mill, 91 by 30 inches, is used for finishing plates of less than 15 pounds per square foot. Both mills are driven from a single horizontal condensing simple engine, 39 inches diameter of cylinder, by 6 feet stroke, developing as high as 800 I. H. P.

This steel was tested at the Norway Works on a Riehlé hydraulic machine of general design as shown in Fig. 6, of 50,000 pounds capacity, new and in good order. It is worked by hand through a single pump to a ram in the lower casing, the load being transmitted through the piece to a lever in the upper casing between stanchions, thence to the open lever at the top, thence down one stanchion to a third lever in

* Pit-scrap consists of the "skull," or layer of steel left on the bottom and sides of the ladle, the overflow of ingots, leakage into the pit, runners, &c.

the casing under the pump, thence up the scale stanchion to the scale beam. The beam is fitted with primary and jockey weights, reading to 10 pounds, and has adjustable compensating attachment. The grips consist of high-faced wedges $5\frac{1}{2}$ by $3\frac{1}{4}$ inches. The packings gave frequent trouble from leakage, necessitating stoppage and overhauling.

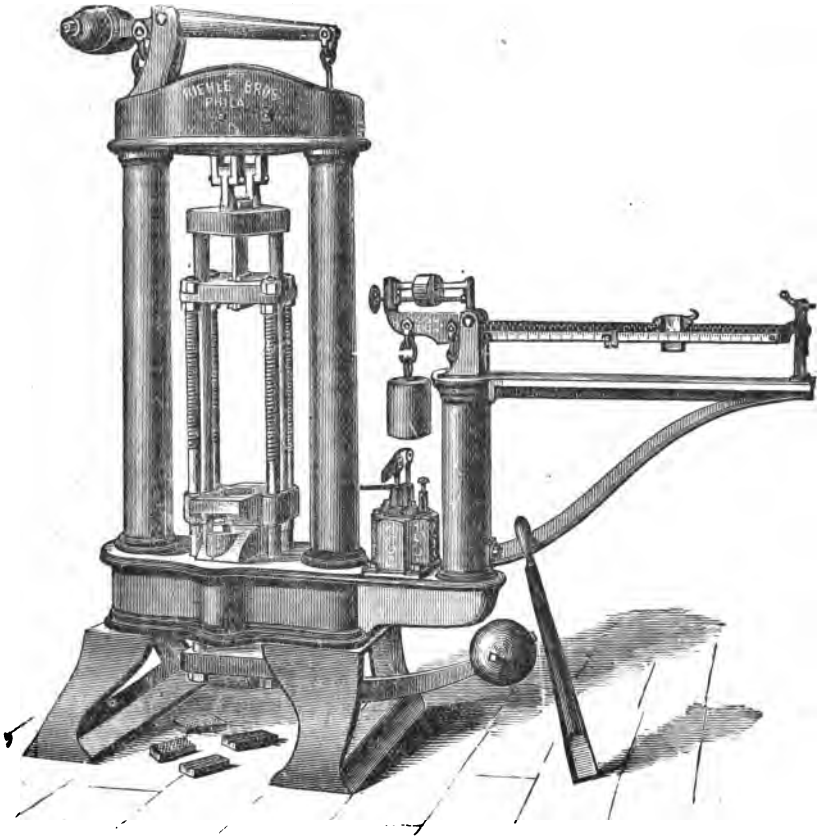


FIG. 6.—50,000 lbs. Riehle Hydraulic Testing Machine used at Norway Iron and Steel Works and at Black Diamond Steel Works.

DIMENSIONS.

Extreme height.....	8 ft.
Extreme length.....	7 ft.
Extreme width	2 ft. 6 in.
Weight.....	2,250 lbs.

ADAPTATION.

Tensile specimens.....	6 in. to 24 in. long.
Round specimens.....	1 in. diam. or less.
Square "	1 in. x 18 in. or less.
Flat "	2 in. or less x $\frac{3}{8}$ in. or less.
Transverse specimens	12 in. long.
Compression "	20 in. high or less.
" surfaces.....	6 in. x 6 in.
Motion of plunger.....	8 in.

The pieces for tensile test were straightened cold from the bent shearing, cut out on a planer, and laid off and measured before and after fracture with Brown & Sharp's gauges. The mean of several measurements was taken for thickness of fractured area.

The pieces for quenching test were cold straightened as left by the shears, and generally heated at a smith's forge, about twelve at a time and two or three deep, in an arched coke fire with closed mouth, but sometimes on a flat fire under a board with slight blast. On cooling in water at 82° F., they were bent under a steam-hammer with a light uniform stroke.

Sufficient chemical information accompanies the report of tests to enable the curve of carbon properties (p. 189) to be constructed, thus showing graphically the average behavior of this material under the tensile tests.

The chemical methods in use are:—for carbon, the color test; for manganese, a volumetric process devised by the chemist of the Norway Works, Mr. H. C. Babbitt, taking only from ten to fifteen minutes for a test, and said to give results which agree well with determinations of eminent chemists using the more common methods. Occasional checks for manganese are also made by the nitric acid and chlorate of potash process.

The total number of heats tested up to September 1, 1884, is 369, of which 61 or 18.7 per cent. were rejected. Of the 308 heats accepted for ship and boiler plate, the average tensile strength per square inch is 62,472 pounds, with a corresponding ductility of 25.56 per cent. in 8 inches. Of the material so accepted, 1,616.22 tons were delivered at the shipyard up to September 1, 1884, while 13.75 tons or 0.85 per cent. of the amount delivered was rejected on the quenching test. The percentage of loss due to rolling and shearing here is estimated at 27 per cent.

Several interesting special tests were made on this steel, which will be found later on under appropriate headings.

In the following table the tests are arranged in the order of heats. It will be noticed that many of the earlier heats, which were too soft for ship plate, for which they were run, would have met the requirements for boiler metal, not at that time ordered.

TABLE V.—*Tensile tests Norway steel.*

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Perct.	Perct.	Perct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
1892 .....	.14	.36	.....	.770	.561	.432	57,779	29.0	48.0	8	R.
1893 .....	.13	.32	.....	1.002	.524	.524	61,500	27.0	43.0	4	A.
1901 .....	.12	.52	.....	.992	.420	.417	67,200	22.0	49.0	6	R.
1908 .....	.12	.48	.....	1.049	.520	.545	58,810	26.5	58.0	6	R.
1910 .....	.15	.37	.....	1.044	.525	.548	58,276	26.0	53.0	8	R.
1912 .....	.14	.47	.....	1.003	.423	.426	65,200	23.0	49.0	8	R.
1914 .....	.16	.43	.....	1.049	.447	.467	61,660	27.0	62.0	4	A.
1918 .....	.13	.42	.....	1.001	.465	.465	64,300	20.5	61.0	6	R.
1920 .....	.13	.39	.....	1.006	.526	.530	60,987	25.0	52.0	4	A.
1923 .....	.12	.42	.....	.977	.442	.415	57,200	26.0	51.0	8	R.
1931 .....	.15	.47	.....	1.004	.451	.453	61,090	24.0	61.0	6	R.
1941 .....	.14	.47	.....	1.018	.478	.488	60,739	23.7	49.0	6	R.
1943 .....	.13	.39	.....	1.023	.420	.430	60,474	25.5	52.0	4	A.
1966 .....	.18	.23	.....	1.003	.423	.426	60,040	25.5	47.0	4	A.
1968 .....	.22	.34	.....	1.004	.516	.518	59,200	25.5	48.0	8	B.

TABLE V.—Tensile tests, Norway steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Per cent.	Per cent.	Per cent.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
1974	.18	.33		1.000	.512	.512	58,900	27.0	49.0	6	R
1975	.18	.31		.998	.510	.509	59,000	26.5	48.0	6	R
1995	.14	.26		.987	.437	.445	60,340	26.0	42.0	4	A
2009	.12	.33		.991	.434	.429	61,625	25.5	51.0	4	A
2013	.15	.23		.998	.450	.449	59,200	26.0	50.0	6	A
2051	.12	.44		.990	.415	.414	60,964	26.0	51.0	4	A
2053	.12	.35		.993	.406	.404	57,248	24.0	50.0	6	R
2055	.16	.42		.999	.490	.490	55,850	26.0	43.0	4	R
2057	.16	.36		.966	.403	.448	60,516	26.0	43.0	4	R
2059	.12	.35		.987	.480	.474	60,450	26.0	39.0	4	A
2063	.12	.33		.986	.462	.455	60,850	26.3	47.0	4	A
2064	.16	.48		.986	.401	.398	61,020	25.3	51.0	4	A
2066	.16	.43		.987	.405	.399	62,393	26.0	54.0	4	A
2070	.13	.45		.991	.465	.461	61,430	29.0	47.0	4	A
2088	.15	.23		.995	.458	.456	60,344	26.3	43.0	4	A
2091	.16	.40		1.001	.465	.465	63,685	26.0	46.0	4	A
2095	.16	.53		1.000	.470	.470	63,049	26.0	51.0	4	A
2097	.18	.36		.998	.452	.451	64,450	26.0	51.0	4	A
2099	.16	.36		.991	.423	.419	63,251	26.0	50.0	4	A
2109	.16	.40		.991	.461	.456	66,721	26.0	49.0	4	A
2111	.12	.46		.990	.464	.458	62,444	27.5	53.0	4	A
2113	.18	.50		1.920	.290	.555	65,791	26.0	60.0	4	A
2115	.13	.32		.983	.466	.460	60,500	26.5	49.0	4	A
2117	.15	.33		.990	.466	.461	60,610	27.0	46.0	4	A
2119	.14	.33		1.920	.290	.557	65,584	29.0	52.0	4	A
2136	.13	.35		1.225	.290	.355	63,080	25.2	59.0	4	A
2138	.18	.45		.984	.420	.417	69,556	25.5	58.0	4	A
2139	.15	.40		1.222	.296	.361	63,323	26.3	44.0	4	A
2140	.17	.37		1.222	.287	.351	63,092	27.5	54.0	4	A
2141	.14	.45		.990	.427	.422	65,196	25.2	51.0	4	A
2143	.14	.29		.986	.424	.420	60,197	25.5	55.0	4	A
2145	.13	.33		.988	.435	.429	62,544	26.0	45.0	4	A
2149	.17	.42		.986	.440	.433	64,908	25.0	46.0	4	A
2151	.15	.31		.988	.431	.419	61,435	27.0	40.0	4	A
2153	.21	.28		.986	.442	.433	71,690	21.3	44.0	6	R
2156	.12	.39		.993	.426	.424	60,662	25.5	44.0	4	A
2160	.13	.39		.985	.443	.436	61,530	28.0	49.0	4	A
2162	.16	.42		.984	.438	.432	60,688	26.2	48.0	4	A
2163	.15	.37		.985	.443	.439	61,300	25.5	50.0	4	A
2164	.16	.38		.983	.441	.434	62,180	27.5	52.0	4	A
2165	.15	.48		.983	.430	.420	63,500	23.0	49.0	6	R
2167	.14	.42		.980	.430	.421	60,615	26.0	50.0	4	A
2168	.13	.39		.979	.415	.406	61,520	25.5	48.0	4	A
2171	.16	.33		.978	.463	.450	60,590	25.5	46.0	4	A
2173	.15	.35		.982	.442	.434	62,220	26.3	44.0	4	A
2175	.17	.42		.989	.43	.418	61,497	26.0	56.0	4	A
2176	.18	.39		.979	.431	.421	63,050	25.5	43.0	4	A
2177	.12	.33		.977	.442	.414	56,745	30.0	40.0	6	R
2178	.17	.33		.988	.418	.413	63,270	23.0	50.0	6	R
2180	.15	.31		.991	.412	.410	59,862	25.0	52.0	4	R
2181	.14	.44		.989	.413	.409	58,996	27.0	53.0	8	R
2182	.14	.31		.988	.425	.420	57,562	25.5	43.0	6	R
2187	.14	.35		.988	.427	.418	61,091	26.5	40.0	4	A
2188	.13	.28		.992	.419	.415	58,800	26.0	49.0	6	R
2189	.15	.36		.992	.421	.418	59,100	25.5	50.0	4	R
2190	.14	.31		.990	.420	.416	60,752	26.5	50.0	4	A
2191	.15	.32		.985	.430	.427	63,967	25.2	50.0	4	A
2192	.13	.28		.990	.417	.411	63,694	27.0	43.0	4	A
2195	.15	.36		.990	.420	.416	60,190	27.5	37.0	4	A
2196	.20	.39		.986	.423	.418	60,938	26.5	41.0	4	A
2197	.16	.30		.987	.420	.413	61,031	25.5	41.0	4	A
2198	.12	.32		.986	.426	.420	61,304	25.5	43.0	4	A
2199	.19	.39		.982	.419	.410	64,070	27.5	47.0	4	A
2200	.23	.28		.978	.407	.398	65,190	25.0	51.0	4	A
2201	.19	.35		.990	.416	.413	63,271	25.0	45.0	4	A
2202	.12	.33		.990	.423	.418	61,417	25.0	44.0	4	A
2204	.14	.31		.979	.414	.403	64,127	25.0	44.0	4	A
2205	.18	.34		.984	.418	.411	62,246	25.0	48.0	4	A
2206	.15	.31		.989	.405	.403	61,267	25.5	49.0	4	A
2208	.12	.24		.982	.419	.411	60,142	26.0	30.0	4	A
2213	.12	.44		.985	.408	.404	60,315	28.5	45.0	4	A
2215	.12	.30		.986	.423	.417	60,555	27.0	40.0	4	A

TABLE V.—Tensile tests, Norway steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Per ct.	Per ct.	Per ct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
2217	.14	.29	.....	.982	.471	.463	60,524	26.0	41.0	4	A.
2222	.18	.29	.....	.985	.424	.418	62,672	25.5	54.0	4	A.
2223	.15	.39	.....	.984	.404	.397	63,081	25.2	50.0	4	A.
2235	.14	.24	.....	.967	.466	.454	60,265	28.2	50.0	4	A.
2226	.15	.39	.....	.965	.422	.409	61,141	25.5	45.0	4	A.
2237	.15	.45	.....	.985	.424	.419	65,796	26.0	51.0	4	A.
2228	.15	.27	.....	.984	.470	.463	63,169	25.0	53.0	4	A.
2229	.14	.23	.....	.987	.462	.456	65,078	26.0	42.0	4	A.
2230	.17	.33	.....	.986	.464	.457	61,866	26.5	49.0	4	A.
2231	.16	.32	.....	.981	.471	.463	62,050	26.0	47.0	4	A.
2232	.16	.30	.....	.980	.430	.423	62,382	26.0	42.0	4	A.
2233	.14	.30	.....	.979	.417	.412	61,939	26.0	49.0	4	A.
2234	.12	.30	.....	.985	.422	.416	61,666	26.0	47.0	4	A.
2235	.15	.21	.....	1.220	.244	.229	62,492	25.0	49.0	4	A.
2241	.15	.33	.....	1.260	.255	.220	65,273	25.0	54.0	4	A.
2242	.15	.36	.....	1.260	.245	.207	69,287	26.0	56.0	4	A.
2243	.19	.36	.....	1.230	.253	.311	66,369	25.0	52.0	4	A.
2244	.17	.40	.....	1.220	.240	.294	65,058	25.0	50.0	4	A.
2245	.19	.32	.....	1.235	.249	.308	65,059	25.0	51.0	4	A.
2246	.18	.31	.....	1.220	.242	.285	65,090	25.0	53.0	4	A.
2247	.16	.38	.....	1.220	.230	.281	63,681	27.0	46.0	4	A.
2249	.19	.35	.....	1.220	.239	.293	67,231	25.0	48.0	4	A.
2251	.18	.33	.....	1.220	.245	.298	67,146	25.0	46.0	4	A.
2253	.15	.29	.....	1.222	.249	.308	63,794	26.0	46.0	4	A.
2254	.13	.33	.....	1.210	.238	.287	66,260	26.0	47.0	4	A.
2256	.15	.31	.....	1.210	.243	.295	65,998	25.0	47.0	4	A.
2258	.12	.39	.....	1.222	.241	.296	64,138	25.0	46.0	4	A.
2260	.14	.26	.....	1.220	.245	.297	64,968	25.0	47.0	4	A.
2262	.14	.36	.....	.987	.240	.237	66,404	25.0	50.0	4	A.
2264	.13	.31	.....	.985	.475	.468	60,910	25.0	49.0	4	A.
2266	.15	.35	.....	.983	.477	.469	62,330	25.0	43.0	4	A.
2268	.21	.41	.....	.987	.473	.467	69,286	25.0	54.0	4	A.
2269	.16	.28	.....	.980	.457	.449	67,682	25.0	53.0	4	A.
2272	.13	.36	.....	.984	.460	.453	59,597	27.0	47.0	6	R.
2275	.18	.35	.....	.983	.469	.461	62,424	25.0	48.0	4	A.
2277	.15	.32	.....	.984	.457	.450	63,966	25.3	48.0	4	A.
2279	.13	.36	.....	.983	.470	.462	60,677	25.0	53.0	4	A.
2281	.12	.27	.....	.980	.460	.451	61,793	25.0	46.0	4	A.
2283	.18	.31	.....	.982	.460	.452	60,712	26.0	47.0	4	A.
2285	.17	.31	.....	.985	.490	.480	63,142	25.3	47.0	4	A.
2286	.18	.34	.....	.981	.463	.454	63,486	25.5	47.0	4	A.
2288	.13	.33	.....	.985	.458	.451	61,287	25.0	46.0	4	A.
2290	.15	.31	.....	.987	.482	.476	61,585	26.0	49.0	4	A.
2292	.14	.27	.....	.987	.306	.304	61,257	25.0	64.0	4	A.
2294	.18	.49	.....	.982	.450	.441	64,820	25.5	45.0	4	A.
2296	.22	.36	.....	.984	.473	.465	61,102	25.0	49.0	4	A.
2298	.15	.31	.....	.981	.476	.466	61,358	26.5	49.0	4	A.
2301	.18	.33	.....	.976	.455	.444	60,231	25.5	49.0	4	A.
2303	.17	.36	.....	.979	.473	.463	62,485	25.5	47.0	4	A.
2305	.12	.38	.....	.981	.477	.467	63,104	26.0	51.0	4	A.
2325	.13	.43	.....	.977	.460	.450	61,957	25.5	53.0	4	A.
2329	.12	.35	.....	.977	.467	.456	62,827	25.0	52.0	4	A.
2330	.18	.43	.....	.975	.475	.463	61,865	25.0	51.0	4	A.
2332	.15	.38	.....	.984	.421	.414	60,600	25.0	41.0	4	A.
2333	.18	.40	.....	.986	.422	.417	64,825	24.0	41.0	6	R.
2334	.14	.33	.....	.983	.421	.412	63,030	25.0	42.0	4	A.
2335	.15	.32	.....	.976	.463	.453	61,944	25.5	41.0	8	A.
2336	.12	.46	.....	.962	.426	.419	59,890	26.0	41.0	8	R.
2337	.13	.36	.....	.985	.422	.417	60,849	26.0	42.0	4	A.
2339	.18	.35	.....	.982	.412	.405	64,759	25.0	43.0	4	A.
2341	.18	.36	.....	.983	.421	.413	61,930	26.3	45.0	4	A.
2343	.15	.30	.....	.971	.469	.456	61,624	25.2	52.0	4	A.
2345	.18	.30	.....	.976	.478	.466	62,821	25.2	53.0	4	A.
2346	.12	.35	.....	.976	.490	.477	61,381	25.0	52.0	4	A.
2348	.12	.36	.....	.981	.455	.444	58,000	22.5	39.0	6	A.
2350	.15	.35	.....	.971	.300	.290	64,294	25.3	49.0	4	R.
2352	.18	.25	.....	.976	.300	.294	63,207	25.2	53.0	4	A.
2354	.13	.30	.....	.977	.476	.465	57,920	20.5	49.0	6	R.
2357	.13	.28	.....	.970	.236	.229	62,158	25.0	53.0	4	A.
2359	.14	.27	.....	.968	.244	.236	60,357	25.0	52.0	4	A.
2361	.13	.27	.....	.989	.281	.279	60,837	25.0	53.0	4	A.
2363	.13	.36	.....	.990	.245	.243	66,936	25.0	61.0	4	A.
2364	.14	.39	.....	.979	.418	.409	58,180	20.5	48.0	6	R.
2365	.15	.34	.....	.984	.241	.237	62,713	25.2	56.0	4	A.

TABLE V.—Tensile tests, Norway steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Per ct.	Per ct.	Per ct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
2368	.14	.25	.....	.976	.286	290	61,177	26.0	52.0	4	A.
2369	.18	.30	.....	.982	.446	438	57,999	21.0	44.0	6	R.
2371	.14	.25	.....	.976	.447	241	64,354	25.0	61.0	4	R.
2373	.17	.40	.....	.984	.418	412	58,006	21.2	46.0	8	R.
2375	.15	.27	.....	.984	.482	473	61,500	25.3	47.0	4	A.
2377	.15	.31	.....	.977	.300	293	62,488	25.2	50.0	4	A.
2379	.19	.35	.....	.975	.300	293	65,713	26.0	51.0	4	A.
2381	.18	.35	.....	.986	.291	287	66,368	25.5	53.0	4	A.
2382	.18	.30	.....	.983	.275	271	64,107	25.0	52.0	4	A.
2384	.18	.45	.....	.989	.297	295	65,026	25.2	53.0	4	A.
2386	.17	.46	.....	.981	.295	290	65,298	25.2	54.0	4	A.
2387	.15	.31	.....	.984	.299	295	63,739	26.3	50.0	4	A.
2388	.27	.29	.....	.974	.299	292	61,545	26.0	49.0	4	A.
2390	.15	.30	.....	.984	.472	464	61,000	26.0	55.0	4	A.
2391	.18	.33	.....	.980	.473	464	61,207	25.2	55.0	4	A.
2393	.18	.37	.....	.983	.472	463	66,047	25.0	58.0	4	A.
2394	.16	.37	.....	.978	.442	471	65,142	26.0	52.0	4	A.
2395	.18	.30	.....	.982	.472	461	60,623	26.0	52.0	4	A.
2396	.19	.30	.....	.982	.473	465	63,703	25.2	52.0	4	A.
2397	.18	.28	.....	.985	.248	242	63,546	25.3	51.0	4	A.
2398	.12	.31	.....	.974	.241	235	64,166	25.3	58.0	4	A.
2401	.20	.30	.....	.975	.247	242	64,039	25.5	55.0	4	A.
2402	.31	.39	.....	.979	.237	232	72,754	25.0	62.0	4	A.
2403	.17	.35	.....	.972	.238	231	70,096	26.0	62.0	4	A.
2404	.16	.33	.....	.982	.470	462	67,057	21.5	51.0	6	R.
2405	.22	.36	.....	.974	.236	228	64,456	25.5	54.0	4	A.
2406	.23	.23	.....	.975	.227	221	69,155	23.0	61.0	4	A.
2407	.14	.34	.....	.974	.237	231	66,350	25.0	56.0	4	A.
2408	.21	.32	.....	.988	.300	297	65,843	25.0	46.0	4	A.
2409	.18	.30	.....	.984	.282	277	63,250	25.3	52.0	4	A.
2410	.18	.31	.....	.982	.300	295	63,382	25.0	47.0	4	A.
2411	.19	.35	.....	.989	.294	293	63,630	26.2	50.0	4	A.
39	.13	.32	.....	.970	.300	290	60,089	27.0	50.0	4	A.
40	.18	.33	.....	.970	.303	294	62,280	25.2	53.0	4	A.
41	.17	.18	.....	.969	.291	281	60,190	26.0	54.0	4	A.
43	.22	.30	.....	.968	.299	290	62,170	25.3	52.0	4	A.
44	.22	.20	.....	.970	.304	295	64,769	24.0	51.0	4	A.
45	.17	.23	.....	.976	.287	280	60,694	26.5	52.0	4	A.
62	.18	.32	.....	.978	.298	293	65,781	23.0	53.0	4	A.
64	.16	.38	.....	.980	.311	305	61,303	26.5	46.0	4	A.
65	.16	.31	.....	.983	.280	280	60,845	28.2	52.0	4	A.
66	.18	.33	.....	.990	.299	299	60,552	27.0	49.0	4	A.
67	.15	.26	.....	.980	.305	299	60,291	26.2	46.0	4	A.
68	.14	.38	.....	.979	.301	294	58,462	28.0	48.0	6	R.
69	.18	.37	.....	.980	.283	280	61,230	21.0	54.0	8	R.
70	.16	.40	.....	.978	.312	305	60,270	27.0	49.0	4	A.
71	.20	.25	.....	.980	.296	290	61,750	24.5	50.0	4	A.
72	.19	.35	.....	.978	.303	297	62,934	24.0	49.0	4	A.
73	.20	.27	.....	.979	.293	290	61,285	25.0	49.0	4	A.
90	.15	.32	.....	.974	.298	291	61,834	25.5	50.0	4	A.
100	.15	.32	.....	.976	.284	278	60,324	25.5	53.0	4	A.
107	.22	.38	.....	.976	.301	294	61,750	26.0	50.0	4	A.
110	.21	.45	.....	.976	.293	286	66,513	24.5	52.0	4	A.
111	.22	.17	.....	.981	.303	298	63,281	24.0	52.0	4	A.
112	.17	.46	.....	.963	.281	271	62,263	27.0	50.0	4	A.
113	.15	.45	.....	.982	.297	293	60,797	25.5	46.0	4	A.
114	.18	.39	.....	.979	.300	294	62,174	25.5	48.0	4	A.
115	.17	.36	.....	.968	.277	268	63,329	25.2	52.0	4	A.
116	.16	.34	.....	.991	.306	304	60,269	25.3	47.0	4	A.
117	.14	.39	.....	.987	.275	271	60,088	27.0	50.0	4	A.
118	.15	.39	.....	.978	.285	279	62,948	28.0	50.0	4	A.
119	.17	.23	.....	.977	.308	302	60,695	26.5	50.0	4	A.
120	.15	.27	.....	.980	.287	281	60,697	26.5	50.0	4	A.
176	.16	.46	.....	.974	.290	281	64,368	24.2	57.0	4	A.
178	.17	.43	.....	.975	.308	300	60,337	24.3	49.0	4	A.
180	.22	.47	.....	.967	.296	283	63,041	23.5	51.0	4	A.
181	.20	.47	.....	.969	.292	282	60,129	27.0	51.0	4	A.
182	.18	.46	.....	.965	.289	279	63,389	25.5	51.0	4	A.
184	.19	.43	.....	.980	.290	285	62,728	24.5	56.0	4	A.
186	.12	.51	.....	.986	.330	325	57,993	26.5	50.0	6	R.
187	.17	.29	.....	.989	.310	307	59,331	25.5	49.0	6	R.
188	.15	.43	.....	.988	.334	334	58,175	24.3	44.0	8	R.
189	.19	.45	.....	.991	.330	326	64,160	24.2	49.0	4	A.
190	.13	.35	.....	.986	.333	329	60,420	24.0	47.0	4	A.

TABLE V.—Tensile tests, Norway steel—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Perct.	Perct.	Perct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
191	.19	.51	.....	.973	.327	.318	63,945	24.5	49.0	4	A
192	.19	.49	.....	.971	.344	.333	62,418	26.0	48.0	4	A
193	.14	.50	.....	.971	.350	.340	56,994	25.3	44.0	6	R
195	.19	.43	.....	.967	.366	.354	62,841	26.0	59.0	4	A
198	.13	.43	.....	.964	.344	.336	60,269	26.0	48.0	4	A
199	.12	.51	.....	.977	.332	.324	62,456	24.0	55.0	4	A
200	.13	.43	.....	.976	.335	.327	62,543	21.5	52.0	4	A
201	.16	.55	.....	.978	.339	.332	60,168	27.0	48.0	4	R
203	.18	.35	.....	.978	.340	.329	60,222	26.0	48.0	4	A
205	.17	.47	.....	.978	.345	.337	61,625	27.0	48.0	4	A
207	.19	.53	.....	.961	.330	.317	63,013	25.0	47.0	4	A
211	.13	.35	.....	.950	.336	.321	62,318	24.3	48.0	4	A
213	.19	.49	.....	.960	.334	.321	61,423	24.3	45.0	4	A
215	.17	.39	.....	.964	.333	.320	60,500	24.5	46.0	4	A
269	.19	.37	.....	.978	.369	.361	63,347	25.0	48.0	4	A
270	.21	.44	.....	.980	.374	.367	64,219	26.0	58.0	4	A
271	.16	.41	.....	.974	.382	.371	60,511	25.3	51.0	4	A
272	.17	.39	.....	.973	.385	.325	65,699	25.3	46.0	4	A
274	.14	.40	.....	.963	.333	.321	60,875	30.0	46.0	4	A
275	.15	.31	.....	.974	.330	.321	61,450	27.0	46.0	4	A
276	.15	.30	.....	.971	.328	.319	64,563	26.5	47.0	4	A
282	.18	.61	.....	.968	.336	.323	66,819	26.2	48.0	4	A
284	.20	.59	.....	.976	.331	.323	71,702	22.3	49.0	6	R
301	.21	.36	.....	.987	.325	.324	62,436	26.0	47.0	4	A
303	.19	.42	.....	.989	.344	.340	62,575	25.3	44.0	4	A
314	.17	.50	.....	.987	.336	.332	64,860	22.2	48.0	8	R
323	.18	.38	.....	.977	.345	.337	59,980	27.0	46.0	4	A
325	.14	.40	.....	.977	.339	.331	60,475	28.0	47.0	4	A
327	.20	.40	.....	.977	.328	.320	60,990	27.0	48.0	4	A
335	.19	.32	.....	.993	.329	.327	59,379	26.0	47.0	6	R
337	.17	.47	.....	1.005	.331	.332	66,761	23.5	49.0	4	A
339	.14	.52	.....	1.001	.326	.326	61,350	26.0	48.0	4	A
341	.13	.37	.....	1.007	.321	.323	58,939	26.3	47.0	6	R
344	.18	.39	.....	1.006	.343	.344	61,279	25.0	45.0	4	A
346	.18	.29	.....	.997	.335	.334	60,597	26.0	45.0	4	A
348	.15	.35	.....	.996	.339	.338	61,946	25.5	46.0	4	A
350	.15	.35	.....	.999	.333	.333	62,152	24.5	47.0	4	A
351	.19	.47	.....	.977	.339	.331	64,403	24.5	46.0	4	A
353	.18	.47	.....	.977	.340	.331	61,882	27.0	44.0	4	A
355	.17	.45	.....	.980	.340	.333	63,222	25.3	48.0	4	A
357	.19	.34	.....	.980	.340	.333	62,846	25.0	45.0	4	A
359	.14	.44	.....	.980	.336	.369	59,608	26.3	47.0	8	R
360	.16	.39	.....	.978	.328	.320	60,544	25.5	47.0	4	A
362	.13	.33	.....	.980	.333	.327	61,811	25.0	45.3	4	A
364	.19	.47	.....	.991	.355	.350	65,727	24.0	45.0	4	A
366	.21	.45	.....	.982	.342	.336	65,152	26.5	47.5	4	A
368	.27	.47	.....	.976	.325	.319	70,532	24.0	49.0	4	A
371	.18	.34	.....	.983	.343	.337	58,311	28.3	45.5	6	R
373	.19	.32	.....	.985	.350	.345	62,839	23.0	45.0	6	R
378	.17	.42	.....	.978	.335	.327	60,617	24.5	47.5	4	A
380	.15	.34	.....	.983	.345	.341	60,387	24.3	45.5	4	A
381	.13	.39	.....	.982	.346	.340	60,740	23.5	45.0	4	A
383	.14	.27	.....	.984	.340	.335	65,660	21.3	57.0	6	R
386	.18	.31	.....	.981	.340	.334	64,142	23.5	57.0	4	A
388	.15	.49	.....	.985	.341	.336	63,027	25.0	46.0	4	A
390	.18	.49	.....	.976	.328	.320	60,097	27.0	46.0	4	A
392	.19	.37	.....	.750	.608	.457	58,822	27.0	47.0	4	A*
394	.20	.37	.....	.977	.323	.318	62,338	25.2	48.0	4	A
396	.15	.22	.....	.978	.336	.328	58,200	25.0	47.0	6	R
398	.19	.43	.....	.973	.348	.338	64,174	25.0	46.0	4	A
401	.17	.53	.....	.974	.343	.334	58,627	28.0	46.0	8	R
403	.18	.43	.....	.962	.346	.339	60,888	27.3	47.0	4	A
404	.23	.39	.....	.979	.347	.339	65,508	25.0	46.0	4	A
410	.13	.30	.....	.750	.593	.445	60,398	25.0	48.0	4	A
421	.19	.45	.....	.975	.338	.330	63,935	25.5	47.0	4	A
423	.16	.55	.....	.978	.345	.337	57,688	27.0	45.0	6	R
425	.18	.40	.....	.970	.348	.338	56,570	28.0	43.0	6	R
427	.20	.37	.....	.981	.338	.326	63,650	24.5	47.0	4	A
442	.18	.39	.....	.977	.323	.315	62,071	27.0	48.0	4	A
443	.18	.57	.....	.972	.345	.335	63,054	25.3	45.0	4	A
444	.17	.26	.....	.973	.338	.329	56,896	28.5	45.0	6	R

* Boiler metal.

TABLE V.—*Tensile tests, Norway steel*—Continued.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Per ct.	Per ct.	Per ct.	Inches.	Inches.	Sq. ins.	Pounds.	Per ct.	Per ct.		
446	.19	.39	.....	.972	.332	324	63,609	26.0	47.0	4	A.
448	.23	.41	.....	.966	.348	336	62,378	25.0	48.0	4	A.
450	.19	.50	.....	.970	.349	339	62,150	26.5	44.0	6	A.
452	.19	.45	.....	.981	.383	376	60,231	30.0	39.0	4	A.
454	.14	.45	.....	.979	.368	360	61,951	25.0	43.0	4	A.
455	.26	.40	.....	.980	.380	373	66,839	25.0	43.0	4	A.
456	.18	.41	.....	.976	.375	366	65,471	20.3	64.0	6	R.
457	.19	.41	.....	.978	.365	357	65,762	23.5	57.0	4	A.
458	.18	.37	.....	.970	.359	352	62,321	24.3	49.0	4	A.
459	.19	.39	.....	.976	.367	357	59,707	27.0	43.0	4	A.
460	.23	.56	.....	.980	.382	375	63,267	25.0	58.0	4	A.
462	.21	.44	.....	.982	.395	388	62,255	25.0	51.0	4	A.
464	.18	.40	.....	.986	.358	354	60,056	27.0	44.0	4	A.
466	.24	.44	.....	.985	.350	344	62,253	28.0	44.0	4	A.
467	.19	.51	.....	.983	.366	352	60,658	26.3	44.0	4	A.
468	.23	.43	.....	.988	.336	333	60,100	27.0	44.0	4	A.
469	.22	.40	.....	.983	.350	344	61,555	25.2	44.0	4	A.
470	.23	.48	.....	.976	.373	364	62,581	27.0	42.0	4	A.
471	.18	.42	.....	.978	.353	345	60,550	25.0	43.0	4	A.
472	.19	.46	.....	.974	.374	364	60,800	27.5	43.0	4	A.
473	.22	.47	.....	.991	.360	357	61,905	23.5	43.0	4	A.
474	.18	.31	.....	.993	.340	338	57,488	28.3	45.0	6	R.
475	.17	.49	.....	.997	.362	361	53,492	27.0	42.0	4	R.
476	.19	.50	.....	.995	.313	313	64,280	24.0	50.0	4	A.
478	.20	.60	.....	.992	.357	354	65,208	25.3	45.0	4	A.
482	.19	.47	.....	.995	.360	358	66,765	24.0	52.0	4	A.
485	.16	.48	.....	.995	.360	358	60,045	27.0	42.0	4	A.
496	.18	.52	.....	.993	.361	359	64,936	24.5	46.0	4	A.
497	.20	.44	.....	.994	.382	381	61,359	27.0	40.0	4	A.
498	.20	.39	.....	.991	.366	364	63,925	25.5	44.0	4	A.
499	.21	.51	.....	.990	.367	363	66,948	23.3	49.0	4	A.
500	.22	.54	.....	.994	.366	363	72,666	23.2	45.0	4	A.
501	.19	.50	.....	.992	.379	376	64,981	24.0	42.0	4	A.
502	.21	.55	.....	.985	.364	358	62,258	24.3	43.0	4	A.
503	.20	.44	.....	.986	.298	294	69,432	17.0	52.0	6	R.
505	.20	.51	.....	.981	.337	330	64,944	25.0	47.0	4	A.
506	.20	.58	.....	.983	.356	350	63,401	26.5	45.0	4	A.
507	.19	.64	.....	.981	.337	331	63,166	24.0	46.0	4	A.
508	.18	.45	.....	.988	.346	342	62,008	25.0	46.0	4	A.
509	.13	.46	.....	.983	.313	307	60,834	25.3	50.0	4	A.
510	.18	.53	.....	.982	.341	335	60,800	26.0	45.0	4	A.
511	.18	.49	.....	.991	.364	360	60,341	27.0	43.0	4	A.
512	.19	.47	.....	.987	.325	322	61,709	25.0	48.0	4	A.
515	.18	.45	.....	.982	.342	336	61,285	26.5	46.0	4	A.
519	.19	.42	.....	.975	.357	348	63,481	26.0	44.0	4	A.
520	.18	.50	.....	.981	.347	341	62,949	25.5	47.0	4	A.
524	.18	.55	.....	.975	.346	338	65,857	25.0	47.0	4	A.
526	.19	.39	.....	.976	.330	323	66,081	25.5	46.0	4	A.
558	.17	.43	.....	.971	.420	399	62,724	23.8	57.0	6	R.*
650	.18	.29	.....	.973	.407	396	60,193	28.7	52.0	4	A.
680	.15	.36	.....	.975	.401	392	60,552	25.0	51.0	4	A.
681	.18	.39	.....	.977	.429	419	61,781	25.2	50.0	4	A.
682	.11	.41	.....	.975	.409	398	61,442	25.5	53.0	4	A.
683	.18	.31	.....	.968	.428	414	56,506	24.3	50.0	6	R.
684	.11	.34	.....	1.005	.400	402	58,271	26.2	51.0	4	A.
685	.15	.41	.....	1.060	.409	433	56,448	27.5	50.0	6	R.
686	.16	.30	.....	.999	.418	418	58,710	27.5	51.0	4	A.
687	.11	.34	.....	1.010	.397	401	57,617	28.5	46.0	4	A.
688	.17	.40	.....	1.022	.395	403	61,744	28.2	53.0	4	A.
676	.16	.42	.....	.969	.418	405	62,500	27.8	50.0	4	A.
677	.14	.34	.....	.969	.394	381	58,950	28.0	50.0	4	A.
678	.12	.36	.....	.972	.390	379	58,080	26.0	51.0	4	A.
679	.12	.43	.....	.970	.420	407	56,334	25.5	50.0	6	R.

* Rejected for boiler metal.

BLACK DIAMOND STEEL.—PARK, BRO. & CO.

(Inspectors, Passed Assistant Engineer E. A. Magee and Assistant Engineer L. D. Miner, U. S. N.)

The material to be supplied consisted entirely of ship-plate, and was produced by the Siemens-Martin process in two 14-ton furnaces. The erection of these furnaces was commenced August 18, 1879, by Messrs. William Swindell & Bros., of Pittsburgh, the first cast being made in 1880. They were subsequently enlarged to 12 tons capacity, and finally, in September, 1883, to 14 tons each. They stand side by side in one pit of 33 feet and 25 feet semi-diameters, and are served by a single ladle, of 15 tons capacity, operated by a hydraulic crane in the center of the pit. The furnaces are 29 feet 7 inches long by 10 feet $1\frac{1}{2}$ inches wide by 10 feet $8\frac{1}{2}$ inches high over all, while the hearth measures 13 feet 6 inches by 10 feet $10\frac{1}{2}$ inches.

Coal-gas was supplied by Siemens producers until February 25, 1884, since which time natural gas, led 18 miles by pipe from Murraysville, Pa., has been used at a pressure of 1 pound to the square inch. It may be interesting to state that its composition varies as follows:

	Per cent.
Marsh gas (CH_4).....	42 to 88
Hydrogen	10 to 39

with carbonic acid (CO_2), carbonic oxide (CO), olefant gas (C_2H_4), and nitrogen in smaller and variable quantities. This gas is admitted cold at the ports of the furnace, the regenerators being used for the air only. It cannot be preheated, on account of the carbon thrown down from the marsh gas depositing itself in a hard layer on the checker-work, gradually clogging it. Nevertheless, it seems probable that the high proportion of hydrogen in the fuel ought, with proper management, to diminish the amount of oxidation in the bath and give a better quality of product, by affording higher temperature with the same amount of air than when ordinary producer-gas is used. No trouble is experienced from variations in its composition, and its use gives general satisfaction and results in a considerable saving in the cost of labor and fuel.

The charge for the mild steel supplied under the Board's inspection consisted of Ridgeway pig from Scotland, containing about $3\frac{1}{4}$ per cent. of silicon and .03 per cent of phosphorus; charcoal-blooms from Chateaugay, Franklin County, New York, containing .015 to .03 per cent. of silicon and .008 to .02 per cent. of phosphorus, with traces of sulphur—these blooms form the bulk of the charge—; steel scrap from plates of this quality, ferro-manganese, generally from Terrenoire, France, and containing 70 to 85 per cent. of manganese and .2 to .3 per cent. of phosphorus. The materials were all charged cold.

Experimental heats were made, using puddled bars from Ridgeway pig. The resulting steel was very soft, giving only 59,000 pounds tensile strength, with .16 per cent. of carbon and .28 per cent. of manganese.

As illustrative of good practice it may be stated that, in addition to those mentioned above, the following materials are used for making other grades of steel than that supplied under this inspection:—Puddle bar; old molds made of Bessemer iron, so that when worn out they may be broken up and used in the steel furnace; spiegeleisen from Northern Germany or the Edgar Thomson Steel Works at Braddock, Pa., and containing 4 to 5 per cent. of carbon, 12 to 20 per cent. of manganese, .5 to 4 per cent. of silicon, .14 to .20 per cent. of phosphorus; red

hematite iron ore from the mines of the Republic Iron Ore Company, Northern Michigan, and containing 64 to 68 per cent. of iron, 2.86 per cent. (or less) of silica, and .03 to .04 per cent. of phosphorus.

It is believed that the proportion of scrap and bloom to pig is always large, so that, although decarburization is assisted by the use of ore in small quantity, the process remains more the "pig and scrap" than the "pig and ore."

The average weight of seventeen heats of metal made under this contract was 27,546 pounds; average time from charging to tapping seven hours, making about fifteen heats from each furnace weekly. Ferro-manganese was added to the bath before tapping.

The size and shape of ingot vary with the plate to be produced, the shape being an approximate parallelopiped, with a taper of one in 60 for stripping, and are different for top and bottom cast. For top cast the molds are 12 by 16 inches at the top and 60 inches high; for bottom cast, a set of molds giving ingots 7 inches thick and 50 inches high by widths varying by 2-inch increments from 18 to 36 inches; also 10 by 24 by 50 inches and 10 by 30 by 50 inches. For bottom cast eight molds are grouped together, with central runner, on a base plate 6 feet 8 inches in diameter.

The inspector reports that it is not thought to effect the quality of the steel whether top or bottom cast is used. Large plates are, however, bottom-poured, and are finished at one heat at the rolls. Lighter plates are top-cast, the ingots worked under the hammer into slabs 6 inches thick and of other dimensions to suit the size of plate, reheated and finished. The hammers used are a 17-ton and a 5½-ton, made by Messrs. Wm. Bement & Sons, Philadelphia, 40 and 26 inches diameter, and 9 and 5½ feet stroke, and strike a blow of 90 and 25 tons, respectively, using steam of 90 to 100 pounds pressure by gauge. With the larger hammer, it is said an average of 40 tons of ingots can be converted into slabs every twenty-four hours.

Two plate-mills are in use. The smaller is an 86 by 26 inch mill with three two-high housings, one cogging and two finishing. It can take an ingot 7 inches thick.

The larger mill is of new pattern and has only been in operation since June 28, 1884. It is a 115-inch three-high mill, with top and bottom rolls 32 inches in diameter and center roll 20 inches. It can take an ingot 15 inches thick and roll plates up to 112 inches width down to $\frac{3}{16}$ inch thick, and of length only controlled by the size of furnaces and facilities for handling, the weight of ingot being limited to 4,500 pounds.

The mill shears have 94-inch knives and can cut plates up to 1 inch thick.

The testing-machine used was a Riehle hydraulic of 50,000 pounds capacity and similar in all respects to that described as in use at the Norway Steel and Iron Works, and illustrated by Fig. 6. It gave considerable trouble from leakage. Pieces for tensile test were straightened cold as left by the shears and cut out in a shaping-machine. They were measured for original width and thickness near each witness mark and in the middle, and a mean taken. Measurements for thickness of fractured area were made at one edge and in the center by sighting with a scale divided into hundredths of an inch, and the mean taken; and the width was similarly measured, the possible error in final area being perhaps as great as 2 per cent. of the original area.

The pieces for quenching test were inserted in a furnace, bent as they came from the shears, brought to the required temperature, removed

and straightened, and plunged into water. The furnace was generally black, with a smoky flame, in contact with the pieces. After hardening they were bent in a form under a steam-hammer to an included angle of about 120°, then around another form to about 20°, and finally directly under the hammer to the required curvature.

Considerable trouble was experienced from this test, which may have arisen from the pieces being heated for some time in contact with a smoky flame, occasionally high in impurities, readily absorbed at the surface of the metal. The irregularities of edge produced by shears are also often of such a kind, depending on the condition of the knives, as to make the piece peculiarly liable to tear from the sheared edges, and if there be any surface brittleness, fracture may be rapid with crystalline surfaces. In such a case, as here, better results would be obtained if the edges were smoothed off with a fine file, as allowed, and the heating done with a clear fire, the flame, if possible, being kept off the pieces.

The exact amount of material rejected on this test cannot be obtained, as it was not convenient to weigh any plates but those to be shipped.

No chemical information accompanies the record of test.

The total number of heats tested to September 1, 1884, was 65, of which 9, or 13.8 per cent., were rejected on the tensile tests. Of the 56 accepted heats the average tensile strength was 63,125 pounds per square inch, with a corresponding average ductility of 25.83 per cent. in 8 inches. Of the material so accepted 287.4 tons were delivered at the ship-yard up to September 1, 1884, while about 24 tons,* or 8.35 per cent., of the amount delivered failed on the quenching test.

The following table gives the result of tensile tests in the order of heats:

TABLE VI.—*Tensile tests, Black Diamond steel.*

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Pr. ct.	Pr. ct.	Pr. ct.	Inches.	Inches.	Sq. inch.	Pounds.	Per ct.	Per ct.		
380				1.250	.297	.371	66,390	26.70	45.8	4	A.
400				1.000	.583	.583	64,815	24.87	50.0	4	A.
412				1.017	.610	.620	61,210	23.90	48.5	4	A.
436				1.007	.611	.611	61,177	23.60	50.0	4	A.
437				1.242	.286	.355	63,765	25.20	49.6	4	A.
438				1.250	.414	.617	61,587	24.50	48.7	4	A.
452				1.005	.595	.598	66,072	23.30	50.7	4	A.
454				1.238	.411	.508	61,665	24.80	48.3	4	A.
456				1.262	.402	.507	68,660	23.00	50.0	4	A.
458				.997	.600	.600	61,332	24.15	50.3	4	A.
478				1.247	.293	.365	72,485	24.60	50.0	4	A.
482				1.261	.467	.588	67,907	25.40	52.5	4	A.
486				1.245	.411	.511	64,460	26.20	48.0	4	A.
492				1.233	.412	.507	64,582	25.60	48.0	4	A.
506				1.245	.286	.356	62,452	25.80	45.8	4	A.
512				1.253	.294	.368	63,740	24.70	45.8	4	A.
536				1.263	.279	.352	60,642	26.31	43.0	4	A.
545				1.262	.352	.444	60,270	27.60	42.5	4	A.
571				1.263	.231	.291	60,605	24.74	47.2	4	A.
581				1.272	.348	.442	62,675	24.15	47.9	4	A.
584				1.222	.462	.564	62,195	26.00	52.3	4	A.
597				1.238	.463	.573	61,015	27.30	44.0	4	A.
601				1.264	.350	.442	65,772	20.78	50.5	4	R.

*This amount is not accurate, being obtained from the proportionate number of plates which failed, the individual weight of such plates not being reported.

TABLE VI.—Tensile tests, Black Diamond steel.

Heat number.	Carbon.	Manganese.	Phosphorus.	Average original width.	Average original thickness.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Accepted or rejected.
	Pr. ct.	Pr. ct.	Pr. ct.	Inches.	Inches.	Sq. inch.	Pounds.	Per ct.	Per ct.		
606				1.263	.462	.583	64,435	24.90	48.8	4	A.
610				1.235	.435	.537	64,430	26.52	47.4	4	A.
612				1.265	.414	.523	69,115	23.06	53.0	4	A.
616				1.233	.474	.584	59,460	28.46	45.1	4	A.
638				1.268	.425	.538	64,537	26.03	48.9	4	A.
640				1.257	.420	.603	64,740	26.91	47.8	4	A.
642				1.254	.476	.596	63,227	26.28	47.0	4	A.
681				1.257	.359	.451	61,545	22.21	43.0	4	A.
694				1.251	.484	.605	62,290	25.62	51.0	4	A.
696				1.254	.417	.522	62,665	27.21	47.0	4	A.
703				1.249	.474	.592	63,352	23.77	47.0	4	A.
712				1.259	.361	.454	62,755	25.99	46.0	4	A.
716				1.014	.517	.324	60,962	23.78	43.0	4	A.
719				1.271	.504	.640	62,997	26.75	45.8	4	A.
721				1.243	.492	.611	63,062	26.56	52.5	4	A.
728				1.000	.541	.541	62,200	26.25	44.0	4	A.
745				1.017	.577	.586	61,510	25.62	48.0	4	A.
794				1.012	.529	.535	59,575	27.78	45.0	4	A.
801				1.226	.467	.572	60,550	28.93	45.0	4	A.
805				.970	.517	.501	63,795	28.30	43.0	4	A.
814				.998	.516	.514	59,445	24.84	46.5	4	A.
837				1.016	.529	.537	61,800	23.30	47.0	4	A.
841				1.028	.525	.540	60,640	27.29	45.9	4	A.
843				1.006	.532	.536	59,990	28.40	42.9	8	A.
862				1.005	.578	.581	58,907	29.23	43.2	4	A.
881				1.011	.562	.589	62,682	25.65	47.1	4	A.
888				1.227	.287	.351	64,402	22.99	46.4	4	A.
891				1.008	.542	.546	62,697	26.57	48.7	4	A.
922				1.253	.282	.353	62,955	27.03	47.0	4	A.
923				1.253	.328	.411	61,575	28.96	44.3	4	A.
924				.979	.693	.679	60,386	26.93	43.6	4	A.
925				1.224	.240	.291	66,325	23.64	46.3	4	A.
926				1.224	.282	.337	66,820	25.97	46.6	4	A.
929				.993	.679	.674	59,835	27.24	42.7	4	A.
930				1.225	.467	.572	58,070	29.80	39.9	4	A.
937				1.227	.238	.293	65,002	26.65	46.9	4	A.
942				1.254	.226	.284	62,062	24.15	43.6	4	A.
951				1.243	.281	.351	63,932	25.67	46.3	4	A.
954				1.243	.470	.585	60,742	27.22	45.8	4	A.
1003				1.260	.369	.466	61,340	28.19	44.0	4	A.
1004				1.282	.290	.369	63,655	23.64	47.1	4	A.

* Annealed.

† One piece gave 20 per cent. elongation.

‡ One piece gave 14 per cent. elongation.

SUMMARY.

Number of tests.	Material.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.
		Sq. in.	Pounds.	Per ct.	Per ct.	
58	Accepted .....	.4998	63,125	25.83	47.16	283
5	Rejected for lack of ductility .....	.4611	62,896	22.61	46.00	20
3	Rejected for lack of tensile strength .....	.5789	58,812	29.16	43.10	12
1	Rejected for lack of tensile strength and ductility .....	.3530	58,222	20.84	42.50	4

CAMBRIA STEEL.

(Inspectors, Assistant Naval Constructor R. Gatewood and Assistant Engineer B. C. Bryan, U. S. N.)

The contract for all the angles, tees, and deck-beams (to which flat bars for edge strips were afterwards added), in amount between one and two thousand tons, required under this inspection, was given by the ship-building contractor to the Phoenix Iron Company of Philadelphia, with works at Phoenixville, Pa. Subcontract was entered into by this company with the Cambria Iron Company, Works at Johnstown, Pa., for the desired amount of material in blooms of required sizes, delivered at Phoenixville, and of such quality as to satisfy the former company that the finished material would meet the requirements. Accordingly, nineteen heats, from 4121 to 4286, inclusive, were first tested by the Phoenix Iron Company's inspector, samples being taken from a flat bar $2\frac{1}{2}$ inches by $\frac{5}{8}$ inch, for tensile strength and ductility, and for hardening qualities by the quenching test. The results of these tests are given in the table, p. 434, in comparison with the tests subsequently made on the finished material of the same heats. All heats subsequent to 4286, and including No. 4285, were tested at the Cambria Iron and Steel Works, under the Board's instructions of October 8 (pp. 33 and 34), the Government inspector accepting or rejecting heats to the Phoenix Iron Company's inspector, under the tensile tests, and the latter, after making a preliminary quenching test, notifying the Cambria Iron Company of the final acceptance or rejection of each heat. The first three heats so tested, 4285, 4301, and 4309, being intended partly for 7-inch deck beams, the test pieces were taken from plates 12 inches wide by $\frac{7}{16}$ -inch thick. For convenience, a flat 6 inches by $\frac{7}{16}$ inch was afterwards taken for test in all cases (with a few accidental exceptions of thicker flats of the same width), as representing the average amount of work on the shapes required, the harder heats being preferably worked into blooms for deck beams, which have less work of reduction than the test piece.

The steel was made by the Siemens, or "pig, scrap, and ore," process—though in some of the heats little or no scrap was used—in two fifteen-ton Pernot revolving furnaces, with 16-foot pans, erected in 1878-'79. These furnaces, with a twelve-ton furnace with 14½-foot pan, now used for dephosphorizing pig-iron by the Krupp washer process, stand in line under one roof, and with charging platform at the same level on the opposite side from the pit, and so high that the tops of the regenerators, which are directly beneath the bearing platform, are four or five feet above the floor level. To each of the larger furnaces there is a separate circular pit sunk 5 feet below the floor level and supplied by independent hydraulic cranes, while a 25-ton Sellers steam crane serves for general purposes, and especially in connection with the washer furnace and its pig bed. Heating furnaces at the rear of the charging platform serve to preheat the pig for the charge. The scrap is charged cold. Gas is supplied by four Siemens producers to each furnace. A hydraulic lift supplies material for the charge and for the cupolas connected with the washing furnace.

The composition of the charges varied widely, except for heats 5216, 5219, 5220, 5221, 5253, and 5255, which consisted entirely of washed metal and hematite ore, and are comparatively low in phosphorus

(below .05 per cent.). There is nothing noteworthy in their tensile tests except an appreciable fall of the elastic limit.

An average of five ingots of 5,500 pounds each was obtained from each heat. The time from charging to tapping was eight hours.

Ferro-manganese was added before tapping, and the bath was then rabled while the hearth revolved, insuring perfect homogeneity in this respect.

The ingots were all top cast and of uniform pattern, being 14 inches square at the top and $18\frac{1}{2}$ inches at the bottom, with corner fillets, and weighing 5,500 pounds each. One ingot of each heat was rolled down in the blooming mill as soon as possible after stripping, and two test billets removed, hammered down to slabs about 3 inches thick, reheated, and rolled down to 6-inch by $\frac{7}{8}$ -inch flats. The remaining ingots were allowed to cool off completely while awaiting the results of the tests, which being reported satisfactory, they were charged in gas furnaces, of which eight, with an aggregate capacity for sixty-four ingots, are worked in connection with the blooming mill.

The blooming train is two-high, with collared rolls 40 inches in diameter, and is driven by a reversing engine with two cylinders 40 inches in diameter and 48 inches stroke, working at 90 revolutions, and geared to the roll train 3 to 1. Half the weight of the upper roll is supported by steelyards in the pit, and its height is controlled by screws worked by hydraulic cylinders, one on each housing, thus allowing several passes through each groove. Hydraulic jaws turn the ingot on the table on each side and direct it to the proper groove.

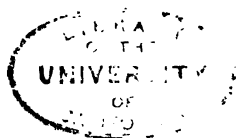
This mill blooms down to 7 by 7 inches, supplying, of course, numerous intermediate sizes. Blooms, of whatever final size, are cut to weight here by hydraulic shears, with due allowance for subsequent heating and rolling. A $2\frac{1}{2}$ -ton steam-hammer, used for hot chipping, stands opposite to the shears.

The foundations for a new 48-inch blooming mill are complete, but its erection will probably not be proceeded with until the decision of Congress with regard to the establishment of a gun foundry, when certain alterations in the mill would render it useful in the manufacture of gun material, and especially of armor plate. Twelve Gjers soaking pits, which keep the ingot at a high temperature by its own heat in cooling in a non-conducting chamber, are placed back of the blooming mill, and have been used intermittently with little success, being too far from the Bessemer house to allow that certainty in handling necessary for working the pits alone without holding the furnaces in reserve for accident.

With the exception of blooms for 7, 8, and 9 inch deck beams, and 5 by 4 inch and 6 by $3\frac{1}{2}$ inch angles, all blooms, after coming from the blooming mill, were reheated and rolled down in a 21-inch three-high mill, to the sizes as under:

Finished shape.	Corresponding size of bloom.
2 by 2 inch angles and under.....	3 by 3 inches.
$2\frac{1}{2}$ by $2\frac{1}{2}$ inches	5 by 3 inches and $6\frac{1}{4}$ by 5 inches.
$2\frac{1}{2}$ by $2\frac{1}{2}$ inches to 5 by 4 inches	$6\frac{1}{4}$ by 5 inches.
5 by 4 inches and 6 by $3\frac{1}{2}$ inches	8 by 4 inches (hammered).
6-inch deck beams	$6\frac{1}{4}$ by 5 inches.
7, 8, and 9 inch deck beams.....	$7\frac{1}{4}$ by 7 inches.

The blooms were shipped under the inspection of the Phoenix Iron Company's inspector, and while the larger flaws had been chipped under



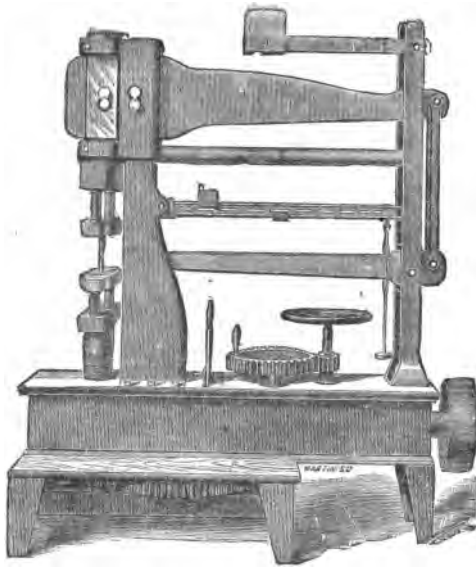


FIG. 7.—100,000 lbs. Gill Screw-Testing Machine used at Cambria Iron Works.

the hammer from the hot 7 by 7 bloom at the blooming mill, flaws in the cold blooms were chipped when considered necessary down to the solid metal.

At the Phoenix Iron Works angles of $2\frac{1}{2}$ by $2\frac{1}{2}$ inches and larger, and all tees and deck beams were rolled on a 20-inch three-high train, driven by a Corliss vertical tandem compound engine using steam of from 60 to 90 pounds pressure. For the deck beams a train of three sets was used, roughers, intermediates, and finishers, and the rolls were 22 inches from center to center, while stronger connections were fitted. The other shapes were rolled in two sets of rolls. This mill is served by four Siemens gas furnaces with aggregate capacity of 48 blooms of ordinary size.

Angles smaller than $2\frac{1}{2}$ by $2\frac{1}{2}$ inches were rolled on a 13-inch three-high mill driven by a Corliss engine of design similar to that of the larger mill. It is served by two smaller gas furnaces.

Both Wilson's and Siemens' producers are used at these works, preferably the former, and fine "buckwheat" anthracite coal has for some time been successfully used.

Flats were rolled on a 10-inch two-high mill, the metal being heated in furnaces using solid fuel.

As this was the first steel rolled at these mills, considerable trouble was experienced at first from overheating the material, but very soon the men exhibited a preference to rolling steel over iron, on account of the greater amount which can be turned out in the same time.

The capacity of the 20-inch mill with strengthened connections being just equal to the manufacture of the 8 and 9 inch deck beams required, a 24-inch mill is now in course of erection with capacity for the largest deck beams, and probably 15-inch I-beams. When it is considered that a 23-inch mill is considered necessary to roll a T-rail $4\frac{1}{2}$ inches high with a 4 inch flange, it appears quite a feat in the art of rolling to have made 9-inch deck beams over 50 feet long at one heat on a mill 3 inches smaller.

Testing at Johnstown.—Producing many grades of steel, from wire-stock and boiler and bridge metal through the grades for rails and the parts of agricultural implements up to the higher spring steels, the Cambria Iron Company has for some time been systematically testing each heat and blow. The testing laboratory is correspondingly well equipped, and the report of physical tests of steel supplied is complete, and, as latterly made, gives as much information from a single test as can well be obtained in the limited time. The laboratory is supplied with two testing-machines, a large horizontal Riehle of old pattern with a capacity of 150,000 pounds, worked by hand, and used chiefly for grading the Bessemer blows, and a Gill machine of 100,000 pounds capacity, worked by belt and gearing from a small vertical boiler and engine in the testing-room, and used for testing wire-stock (Bessemer and open-hearth), boiler, ship, and bridge material, spring steels, and the open-hearth product generally. In this machine (see Fig. 7), the motion of the lower cross-head or wedge-block is given by a vertical screw of large diameter and fine pitch, moving in a nut turned by gearing from a shaft within the framework. This shaft revolves either by gearing from a hand-wheel for small motions, or through paper-faced friction-cones by belt and gearing from the engine. The load upon the test piece is transferred by the upper wedge-block to a lever at the top of the machine, and thence, through the lower lever shown in the cut, to the beam-arm. The load is gauged by a system of weights hanging by a stirrup from the end of the beam-arm, and giving increments of 10,000 pounds for each weight

added, a second weight sliding on the top of beam-arm gauging up to 10,000 pounds by increments of 1,000 pounds, while the jockey-weight, sliding on the under side of the arm, gauges to 1,000 pounds by increments of 10 pounds. The machine was well made and the beam-arm very sensitive. One advantage which this, in common with all screw-machines, has over the hydraulic machines, is that any failure to hold up a load once applied is due entirely to the yielding of the test-piece, and not to leakage of valves, so common in hydraulic machines. This renders observations for modulus of elasticity on the short test piece much more reliable by keeping the stress perfectly constant, and further allows the principal elastic limit (see p. 132) to be accurately obtained from the behavior of the beam-arm. The wedges are flat and single, that is, no liners are used, and are connected in pairs by sliding bars in the sides, which, with finger-holes near the top of the upper pair of wedges, enables this pair to be handled together, while the lower pair always remain in the wedge-block.

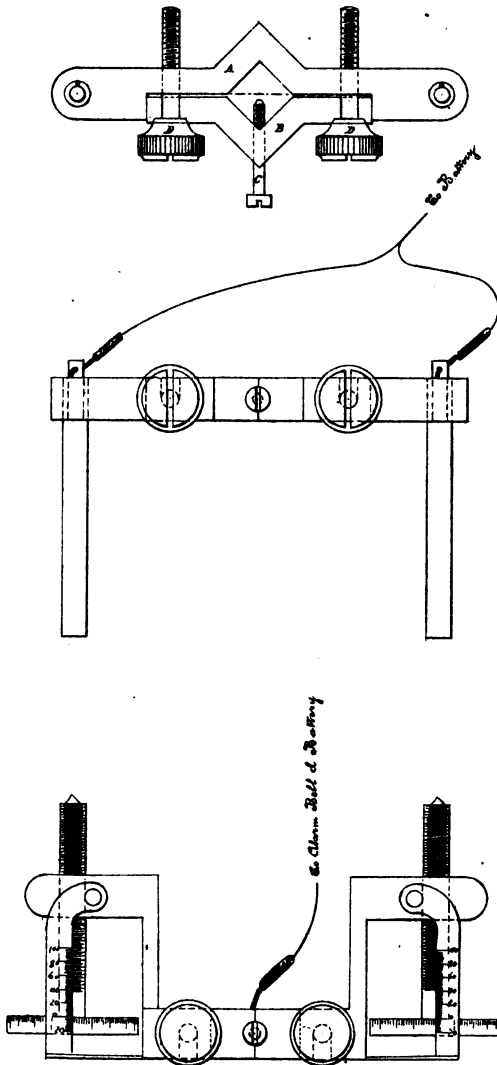
The tensile test pieces were cut out by a slotting-machine and were fairly well shaped. The measurements of the test piece were made by a special sliding micrometer-gauge—measuring to $\frac{1}{10000}$ th of an inch and tested for accuracy—to which the test-piece is brought, and the inspector reports that this is at once quicker and more accurate than measuring with the small portable gauges. The measured length, with intermediate inches when desired, was scribed in with the notched gauge described (p. 93), which, or a similar one, with vernier, was used for measuring elongations, reading off in per cent. directly.

Observations for stretch under stress below the elastic limit, whence the modulus of elasticity is obtained, were made by one of Olsen's electric contact micrometer-gauges (Plate IX.), reading to the $\frac{1}{10000}$ th of an inch. This instrument, though working well with rounds and squares, was not well suited for flat bars, in not affording proper bearings at the clamps, thus causing the arms to tip irregularly and not return exactly to the original reading on removing the stress. This may have been partially due to the fact that the initial stresses 30,000 and 35,000 pounds per square inch were somewhat higher than generally used in obtaining the modulus. These results, the only ones of the kind obtained during this inspection, are considered on page 136.

What may be called the principal elastic limit, or the point at which the strain becomes altogether disproportionate to the stress (see p. 132), was accurately noted in all tests made at Johnstown, and is contained in the tables, besides being plotted in average as a curve of carbon properties, the regularity of which is especially noticeable. In observing this quality, the cracking of the scale was always observed as complementary to the beam indications as described on page 131.

Measurements for final area were made by bringing the fractured piece to the micrometer-gauge and measuring the least width and thickness; the latter on each edge and in the center. The mean of the three thicknesses was taken as the mean thickness.

Testing at Phoenixville.—The testing-machine at the Phoenix Iron Works was supplied by Messrs. Kiehl Bros. & Co., and is illustrated by Fig. 8. It is a hydraulic machine of 150,000 pounds' capacity, worked by hand-lever through a coarse and a fine pump, thus not supplying continuous motion to the wedge-block. The load is transmitted by a double-lever system to the beam-arm, which is supplied with an adjustable compensating weight. The primary scale has a tipping weight, and is notched every 2,000 pounds up to 150,000 pounds; the jockey-weight



Ohm Electric Contact Micrometer
used at the Cambria Iron Works.



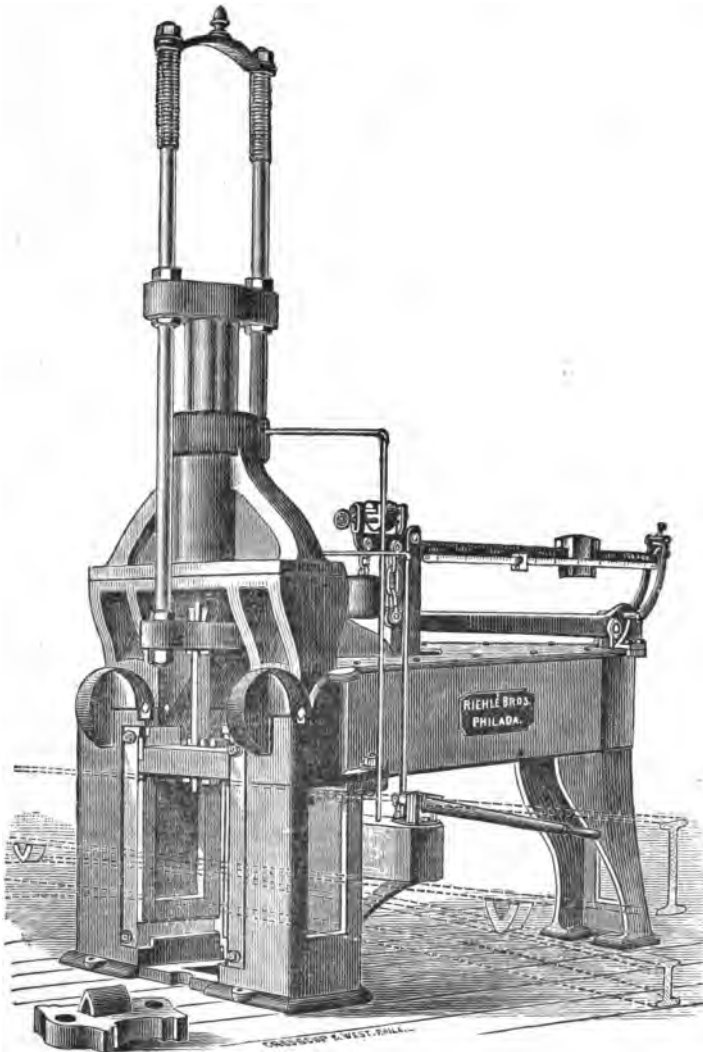


FIG. 8.—150,000 lbs. Riehle Hydraulic Testing Machine used at Phoenix Iron Works.

DIMENSIONS.

Extreme height	11 ft.
Extreme length.....	8 "
Extreme width	5 "
Weight.....	10,785 lbs.

ADAPTATION.

Tensile specimens	12 in. to 4 ft.
Round "	2½ in. or less.
Square "	2 in. x 2 in.
Flat "	3¼ in. or less x 1 in. or less.
Transverse "	1 ft. to 4 ft.
Crushing "	2 ft. or less.
" surfaces	8 in. x 13 in.
Motion of plunger	18 in.

slides continuously on the side arm, which is divided by increments of 10 pounds up to 2,000 pounds.

The tensile test pieces were extremely well made, being cut out on a planing-machine by a careful workman. Measurements were made with a Brown & Sharp's screw-gauge of 1 inch gap and a sliding gauge of very fine workmanship. Here, as at Johnstown, the width and thickness of the specimen were measured at the middle of the length and near each witness mark, in order to find any defect of area at any one place sufficient to cause serious diminution of ductility. In measuring test pieces from the finished shapes, the thickness was obtained at equal distances from the two edges, on account of the taper in the thickness of angle flanges, &c. The fractured area was measured as at Johnstown, except that the gap-gauge was used.

The values of the principal elastic limit given in the tables for the finished material were obtained by noting the cracking of the scale on the piece, the beam indications with the slightly leaking valves not being reliable.

In making the quenching tests here, the pieces* were heated generally in a smith's forge with blast in a hollow fire, either roofed with wet coke or with a board laid over the top and covered with pressed coke. Sometimes they were heated in a small furnace burning soft coal. On one occasion about sixty pieces were placed five or six at a time on the top of a close anthracite fire under a small vertical shop boiler, being thus slowly heated to exactly the desired temperature and perfectly uniformly. All of these pieces failed to bend as required, some of them cracking all across with bright crystalline fracture at the first blow of the hammer and with no reduction at the fracture, while second pieces from the same bars heated as usual passed the test well. It is regretted that the cause of this behavior could not be exactly defined. It plainly consists in the surface absorption of some brittle-making element from the fuel, most probably of sulphur, though it has been proposed that, the atmosphere surrounding the pieces being highly carbonaceous (the fire was dull, and the pieces were twenty to twenty-five minutes heating), the trouble might arise from a surface cementation or absorption of carbon itself. At all events this extreme case illustrates the well-known necessity of using pure fuel in heating, and especially in making expensive flangings, and points to a possible solution of some of the inexplicable fractures of such plates, while it conclusively shows that the circumstances of making this apparently simple hardening test need some attention.

A moderate blast was used in heating afterwards, and anything like a smoky fire avoided, with a very small proportion of failures.†

The pieces for this test were bent by a fuller under a small steam hammer in a hexagon form (used for shaping nuts) to an included angle of 60°, and then closed under the hammer tup to the desired extent.

* The pieces for quenching tests were always the crop-ends of bars, and were generally removed by the hot saw at the rolls. In the event of failure a second piece was taken from the perfectly sound bar.

† It may also be mentioned in this connection that the pieces of the finished material at Phoenixville behaved very much better under the test than pieces of the same heat tested at Johnstown by the Phoenix Iron Company's inspector, though the former had a rough-sheared edge, the corners only being slightly smoothed, while the latter were planed out. The pieces tested at Johnstown were generally heated in the gas-preheating furnace back of the open-hearth steel furnaces, and in an atmosphere of course as little oxidizing as possible. The only essential differences in physical condition were the hammering from 7 by 7 inch bloom to a 3-inch slab at Johnstown and one less heating than in most of the finished material.

The total number of heats tested by the Government inspector up to September 1, 1884, is 152, of which 19, or 12.5 per cent., were rejected, including three which, after passing the tensile tests, were rejected by the Phoenix Iron Company's inspector at Johnstown on his preliminary quenching test. Of the 133 accepted heats the average tensile strength was 64,020 pounds per square inch, with a corresponding average ductility of 25.52 per cent. in 8 inches. A complete summary of the results of the tensile tests is given on page 75. Of the material so accepted, 1,053 tons were delivered at the ship-yard up to September 1, 1884, while 3.41 tons, or .324 per cent., of the amount delivered was rejected on the quenching test, and 4.09 tons, or .388 per cent., on the quenching and cold tests. Particulars of these tests will be found in the general summary, p. 76.

Sufficient chemical information accompanies the report of tests to enable the curve of carbon properties (p. 190) to be constructed, illustrating the average behavior of this material under the tensile tests.

The chemical methods in use at the Cambria Iron Works for the soft steels are—for carbon, the color test; for manganese, the acetate of soda and bromine process; for phosphorus, the molybdate of ammonia process, weighing the yellow precipitate after drying always for the same time at the same temperature. The piece for chemical test was always chipped from the bloom when cut to length at the blooming-mill.

The average carbon of accepted heats was .163 per cent.; average phosphorus for 17 heats, .0875 per cent.; average manganese for 50 heats, .443 per cent. This steel carries considerably higher phosphorus and manganese than that shipped by any of the other works, yet with no injurious results. It is to be remembered, however, that it was made by a different process.

Table VII. gives the results of all tensile tests made on the finished material at the Phoenix Iron Works. Lot 1 consisted of eight bars from Bessemer blooms ordered from the Pittsburgh Steel Casting Company, and is seen to be of very fine quality. The bar marked SP2 is one from two experimental blooms ordered from the Pennsylvania Steel Company, Steelton, Pa., and was of too soft material. Analysis gave $C=0.08$, $Mn=.0387$, $P=0.044$. Lots 18 and 23 are of Cambria Bessemer steel, giving the very excellent average of 66,148 pounds tensile strength with 24.98 per cent. ductility.

It may be remarked that notwithstanding the excellent tests obtained from Bessemer steel, the Phoenix Iron Company preferred to pay more for open-hearth blooms.

Piece 25 I, which gave the very fine result of 62,513 pounds tensile strength, with a final stretch of 30½ per cent., upon subsequent special analysis gave $C=.155$, $Mn=.534$, $P=.089$, showing no peculiarity, the manganese alone being somewhat above the average.*

The figures for the chemical elements in the table are as supplied by the manufacturer, from analysis of a chipping from a bloom of the heat.

* Borings for this analysis were taken from that part of the piece which had necked at fracture.

TABLE VII.—Cambria steel. Tensile tests of finished material.

Heat.	Carbon.	Manganese.	Marks.	Original width.	Original thickness.	Sectional area.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Final elongation in 8 inches.	Final width of original	Final thickness of original	Final area of original area.	Time of test.	Size of bar tested.	Nature of steel and remarks.
B. S.			1 A.	Inches. 1.260	Inches. .380	Sq. ins. .4788	Pounds. 67,356	Pounds. 67,356	Per ct. 26.56	Per ct. 72.2	Per ct. 64.0	Per ct. 46.24	Mins. 16	4 by 3 inch angle	Bessemer steel supplied by Pittsburgh Steel Casting Company.
B. S.			1 B.	1.270	.380	.4826	66,307	66,307	25.50	72.4	66.7	45.30	15	do	
B. S.			1 C.	1.270	.380	.4826	66,307	66,307	25.09	72.4	65.8	47.66	15	do	
B. S.			1 D.	1.260	.380	.4788	67,878	67,878	23.12	73.8	66.7	49.20	16	do	
B. S.			Sp. 2.	1.251	.379	.4737	57,990	57,990	26.94	67.9	57.2	38.88	12	3 by 3 inch angle	Bessemer steel supplied by Pennsylvania Steel Company.
			2 B.	1.250	.327	.4088	62,622	62,622	25.63	74.4	65.2	48.53	13	3 by 2 1/2 inch angle	
			2 C.	1.250	.327	.4088	64,595	64,595	25.38	74.9	67.6	50.61	14	do	
			3 F.	1.215	.327	.4068	62,980	62,980	27.31	72.3	64.2	46.41	15	do	
			3 G.	1.245	.327	.4009	62,733	62,733	25.63	71.5	64.2	45.87	13	do	Do.
			4 C.	1.246	.340	.4236	65,156	65,156	27.90	73.4	65.3	47.95	15	do	
			4 P.	1.239	.339	.4244	65,386	65,386	28.90	72.8	69.8	50.86	15	do	
			5 A.	1.235	.330	.4085	63,035	63,035	26.62	73.5	64.6	47.51	12	do	
			5 B.	1.238	.318	.3985	63,160	63,160	24.38	73.3	65.0	47.64	13	do	Do.
			6 A.	1.243	.322	.4002	65,842	65,842	27.62	76.3	71.3	54.38	15	do	
			6 D.	1.242	.318	.3949	65,052	65,052	25.40	72.5	62.9	47.57	14	do	
			7 A.	1.241	.318	.3946	64,037	64,037	28.00	72.5	69.8	44.08	14	do	
			7 D.	1.252	.327	.4094	65,217	65,217	26.08	73.9	69.1	51.05	15	do	Do.
4127	.15	.35	8 I.	1.246	.306	.3813	64,254	64,254	26.94	74.1	69.3	51.32	14	do	
4140	.17	.54	8 Q.	1.253	.315	.3947	64,479	64,479	28.27	73.3	69.8	51.22	14	do	
4123	.15	.39	7 N.	1.256	.335	.4148	67,936	67,936	22.40	77.4	71.2	55.13	15	do	
4139	.21	.37	9 B.	1.241	.314	.3893	63,630	63,630	24.38	74.1	64.8	48.00	14	do	Do.
4139	.21	.37	9 D.	1.231	.318	.3930	62,596	62,596	26.50	72.8	67.9	45.80	13	do	
4124	.15	.55	10 C.	1.221	.322	.3932	64,600	64,600	26.33	74.1	67.0	49.64	14	do	
4124	.15	.55	10 I.	1.230	.308	.3850	63,375	63,375	24.47	74.2	66.2	49.13	14	do	
4139	.21	.37	11 C.	1.250	.308	.3850	62,727	62,727	27.63	73.6	63.2	46.52	13	do	Do.
4139	.21	.37	11 L.	1.238	.413	.5113	62,390	62,390	25.39	71.6	66.7	47.78	13	do	
4138	.21	.40	12 B.	1.250	.380	.4750	64,842	64,842	24.44	75.1	67.9	50.95	14	do	
4138	.21	.59	12 K.	1.245	.402	.5005	63,256	63,256	24.63	74.0	65.1	48.15	14	do	
4121	.14	.28	13 C.	1.246	.397	.4946	63,485	63,485	28.61	74.0	70.7	52.33	14	do	Do.
4121	.15	.39	13 M.	1.250	.381	.4876	62,448	62,448	25.15	73.0	67.3	48.48	13	do	
4123	.15	.39	13 Q.	1.249	.394	.4905	60,958	60,958	27.92	71.3	65.8	46.89	14	do	
4138	.21	.40	14 D.	1.243	.386	.4798	61,494	61,494	25.97	71.8	65.3	46.89	13	do	

4138.	21	40	14	H.	1.253	395	4911	65,864	26,38	73.8	63.9	50.83	Do.
4140.	17	54	15	D.	1.248	378	4710	63,907	27.00	74.0	63.5	48.53	Do.
4134.	21	59	15	O.	1.249	385	4809	64,150	23.94	76.1	69.2	52.61	Do.
4121.	14	16	B.	B.	1.250	379	4788	62,471	28.75	72.5	68.0	49.05	Do.
4122.	15	28	16	L.	1.240	380	4712	62,712	24.20	72.5	69.2	49.05	Do.
4127.	15	35	17	B.	1.250	388	4850	68,454	23.37	76.0	70.6	53.63	Do.
4123.	15	39	17	G.	1.245	384	4777	64,784	23.66	74.7	68.9	51.50	Do.
B. S.	18	18	B.	B.	1.227	339	4160	67,097	23.08	73.6	65.7	48.34	Do.
B. S.	18	18	F.	F.	1.226	331	4058	66,751	23.45	77.1	74.7	57.59	Do.
4166.	15	19	B.	B.	1.233	346	4266	67,042	23.68	74.5	67.3	51.85	Do.
4166.	15	19	E.	E.	1.224	340	4162	65,833	27.29	73.8	70.3	45.86	Do.
4166.	15	20	C.	C.	1.230	386	4748	62,314	23.78	72.4	68.1	45.86	Do.
4166.	15	21	A.	A.	1.234	388	4760	62,290	23.35	71.6	65.2	46.70	Do.
4166.	15	21	E.	E.	1.230	388	4723	62,884	23.38	72.8	64.7	47.06	Do.
B. S.	22	A.	M.	M.	1.234	373	4603	65,011	25.12	73.0	67.9	49.44	Do.
B. S.	23	C.	G.	G.	1.232	373	4595	65,696	23.38	73.7	67.9	50.00	Do.
4257.	18	23	G.	G.	1.234	377	4595	40,370	25.00	72.6	68.8	49.14	Do.
4257.	18	25	H.	H.	1.242	340	4223	41,321	26.77	74.2	68.7	49.44	Do.
4257.	18	25	J.	J.	1.250	383	4162	41,206	26.16	73.0	68.1	51.83	Do.
4257.	18	25	L.	L.	1.239	384	4758	38,178	26.99	74.1	67.4	48.35	Do.
4257.	18	25	S.	S.	1.245	388	4837	37,777	28.95	72.2	67.4	48.35	Do.
4257.	18	25	S.	S.	1.263	415	5250	62,513	28.35	71.8	67.4	48.35	Do.
4257.	18	26	B.	B.	1.270	410	5207	69,714	26.28	73.1	75.0	53.61	Do.
4257.	18	26	H.	H.	1.250	416	5200	41,346	27.53	73.0	68.2	47.40	Do.
4265.	20	27	L.	L.	1.270	354	4496	40,700	25.86	74.8	68.2	51.00	Do.
4264.	16	28	A.	A.	1.254	358	4449	40,100	25.19	73.8	65.1	48.01	Do.
4265.	20	28	G.	G.	1.271	368	4618	42,257	25.19	74.7	69.7	52.10	Do.
4265.	20	29	H.	H.	1.255	368	4625	38,978	23.94	71.0	63.7	45.28	Do.
4286.	14	26	30	E.	1.264	360	4550	38,780	24.46	74.2	70.0	52.94	Do.
4286.	14	26	30	H.	1.255	368	4559	38,670	24.36	74.7	69.6	52.00	Do.
4286.	14	26	31	A.	1.268	367	4585	38,605	27.81	73.1	65.1	46.94	Do.
4286.	14	26	31	G.	1.263	363	4585	38,440	26.21	72.5	69.3	50.04	Do.
4127.	15	35	32	B.	1.250	413	5162	38,209	29.75	71.7	63.8	45.74	Do.
4127.	15	35	32	D.	1.250	429	5362	38,791	27.93	71.1	68.8	48.24	Do.
4127.	15	34	33	F.	1.252	455	5696	38,414	26.30	73.2	67.4	48.66	Do.
4123.	15	39	34	F.	1.250	454	5675	40,352	26.45	73.6	72.2	53.12	Do.
4122.	15	39	34	H.	1.252	435	5446	38,500	27.00	70.9	70.8	50.22	Do.
4263.	20	35	G.	G.	1.262	403	4949	38,900	26.63	70.1	65.1	45.69	Do.
4261.	15	36	B.	B.	1.244	394	4710	64,154	28.50	73.1	65.7	47.33	Do.
4261.	15	36	G.	G.	1.260	390	4915	65,768	25.80	75.1	69.1	51.85	Do.
4139.	21	37	37	N.	1.268	393	3942	38,658	25.00	72.2	68.8	50.20	Do.
4139.	21	37	37	Q.	1.271	388	4245	40,050	23.50	73.7	68.9	50.82	Do.
4265.	20	37	38	B.	1.251	391	3926	40,643	23.50	73.6	68.6	48.95	Do.
4260.	18	39	B.	B.	1.268	385	3715	41,857	23.50	73.8	69.6	51.38	Do.
4260.	18	39	E.	E.	1.269	385	4863	61,024	23.38	71.9	67.6	48.66	Do.
4139.	21	37	40	A.	1.270	390	4863	38,500	26.11	71.6	64.0	48.38	Do.

11590 M 2 5

TABLE VII.—Cambria steel. Tensile tests of finished material—Continued.

Heat	Carbon.	Manganese.	Marks.	Original width.	Original thickness.	Sectional area.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Final elongation in 8 inches.	Final width of original	Final thickness of original	Final area of original area.	Time of test.	Size of bar tested.	Nature of
				Inches.	Inches.	Sq. ins.	Pounds.	Pounds.	Per ct.	Per ct.	Per ct.	Per ct.	Mins.		
4280	.18		41 A	1.242	.396	.4918	37,820	61,407	23.60	71.1	63.9	46.85	13½	5 by 3 inch angle.	Cambria O. H. steel.
4280	.18		41 X	1.248	.421	.5254	38,820	62,809	22.75	73.2	67.0	49.05	14½	do	Do.
4283	.18	.26	42 E	1.260	.397	.5002	37,685	62,675	23.74	72.4	67.2	48.62	15	do	Do.
4283	.18	.26	42 J	1.255	.396	.4970	37,808	63,078	23.53	74.1	71.5	52.96	14½	do	Do.
4283	.18	.26	43 B	1.255	.408	.5120	37,695	61,719	25.25	72.7	66.0	48.03	14½	do	Do.
4283	.18	.26	43 C	1.246	.409	.5096	37,186	58,963	25.63	70.3	63.4	44.58	12½	do	Do.
4281	.15		44 A	1.255	.408	.5120	37,305	62,665	25.92	71.4	65.7	46.90	14	do	Do.
4281	.15		44 H	1.242	.408	.5042	36,690	59,262	29.08	69.8	63.8	44.52	14½	do	Do.
4257	.18		45 A	1.255	.408	.5120	37,890	67,188	21.63	77.5	71.3	55.29	17½	do	Do.
4257	.18		45 J	1.244	.411	.5113	37,962	63,466	28.11	72.0	65.0	48.84	16½	do	Do.
4263	.20		46 E	1.255	.399	.5007	39,145	65,708	22.81	70.1	68.2	46.45	18	do	Do.
4263	.20		46 F	1.244	.396	.4926	38,773	63,134	27.63	71.7	65.3	46.84	17½	do	Do.
4283	.18	.31	47 A	1.257	.414	.5204	39,565	66,007	24.79	73.1	68.8	50.33	17	do	Do.
4280	.18		48 E	1.257	.397	.4990	37,775	63,725	26.60	72.2	68.3	49.32	16½	do	Do.
4280	.18		48 E	1.257	.410	.5154	37,737	61,602	26.10	73.2	65.4	47.82	14½	do	Do.
4283	.20		49 Q	1.240	.383	.4749	37,000	63,803	23.28	74.9	70.1	52.50	14½	6 by 3½ inch deck beam	Cambria O. H. steel. Broke through deep flaw.

Table VIII. affords a comparison of the tests of $2\frac{1}{8}$ by $\frac{5}{8}$ inch flats at Johnstown with tests of the same heats as finished material at Phoenixville. The form of test piece was the same in both cases. It is seen that with about 60 per cent. of the thickness and sectional area of the test pieces taken from the flats, about 70 per cent. of the reduction of area in the rolls from the ingot, and 63 per cent. greater reduction of thickness from the ingot, the finished material shows a gain of 2,359 pounds, or 3.85 per cent. in tensile strength, while the ductility remains unchanged. The interest of the comparison is, however, interfered with by the fact that the tests were made on different machines. Thus, taking the results of the special comparative tests of material on each machine with tests of corresponding pieces of the same material on the machine at the Washington navy-yard (p. 525), we find that the Gill machine at Johnstown showed 160 pounds less, while the Riehle at Phoenixville showed 2,610 pounds more, than the Rodman at the navy-yard for results from 60,500 to 63,500 pounds. Thus the apparent excess of the Riehle over the Gill machine between these loads is 2,770 pounds. It is not believed, however, that this difference is, even in great part, due to differences in the machines, for it will be observed that the lower tensile strength obtained from the Phoenixville material at the navy-yard is accompanied by considerably greater ductility.

If we admit the accuracy of the machines and neglect the influence of the difference in thickness of test piece, the gain of 3.85 per cent. in tensile strength of the finished material would appear to be due essentially to its increased work of reduction of thickness from the ingot, the proportion being 1.63 to 1.

Upon this comparison, taking the shapes in the table as a fair average for the whole order, was based the size of the flat, 6 inches by $\frac{7}{8}$ -inch, subsequently adopted as representing the average finished material for purposes of test, this flat having almost exactly the same amount of reduction of area from the ingot as the above average for finished shapes, while the reduction of thickness allows a margin in being less than the average for the finished shapes in the proportion of 37 to 42.3.

It may be remarked that if the probable influence on the ductility of the law of proportion of the test piece (to be discussed later) be taken into account, the ductility of the material tested at Johnstown would have been only 25.65 instead of 26.05 per cent. if tested in a piece of dimensions proportionate to those of the test pieces used at Phoenixville. The inference, therefore, is that the increased work of reduction from the ingot has affected an increase of both tensile strength and ductility.

TABLE VIII.—Comparative tests of material of the same heats, with different amounts of work of reduction from the ingot.

Heat.	Carbon.	Manganese.	Average sectional area.	Average ultimate strength per square inch.	Average final elongation in eight inches.	Time.	Average original thickness.	Average reduction of area from the ingot.	Average reduction of thickness from the ingot.	Number of tests.	Size of bars tested.
4, 121	14	.....	Sq. inches.	Pounds.	Per cent.	Mins.					
4, 121	14	.....	.7669	60,372	26.37	25	.610	142.5	26.23	1	Flats, 2 1/2" by 4 1/2"
4, 121	14	.....	.8442	62,978	26.68	14	.388	97.0	41.24	2	Angle, II of 4" by 3" by 9 lbs.
4, 122	15	28	.7699	59,485	28.75	21	.610	142.5	26.23	1	Flat, 2 1/2" by 3"
4, 122	15	28	.5011	62,377	25.32	13 1/2	.402	100.0	39.80	3	Angle, II of 4" by 3" by 9 lbs.; I of 3" by 8 lbs.
4, 123	15	39	.7875	62,603	23.50	20	.625	109.0	25.69	1	Flat, 2 1/2" by 3"
4, 123	15	39	.4816	64,522	26.25	15	.387	142.5	41.35	4	Angle, II of 3" by 3" by 9 lbs.; I of 3" by 8 lbs.; I of 3" by 2 1/2" by 6 lbs.
4, 124	15	55	.7506	60,119	26.12	20	.605	142.5	26.45	1	Flat, 2 1/2" by 3"
4, 124	15	55	.3966	63,988	25.40	14	.321	142.5	49.85	2	Angle, II of 3" by 3" by 2 1/2" by 6 lbs.
4, 127	15	35	.7688	61,589	26.25	20	.620	142.5	25.81	1	Flat, 2 1/2" by 3"
4, 127	15	35	.4787	64,411	23.89	13 1/2	.384	112.5	41.68	4	Angle, II of 3" by 3" by 8 lbs.; I of 4" by 3" by 9 lbs.; I of 3" by 2 1/2" by 6 lbs.
4, 134	21	59	.7688	60,939	23.87	18 1/2	.615	142.5	26.02	1	Flat, 2 1/2" by 3"
4, 134	21	59	.4907	63,703	24.24	15	.304	97.0	40.60	2	Angle, II of 4" by 3" by 9 lbs.
4, 135	21	40	.7844	62,468	25.50	17	.625	142.5	25.60	1	Flat, 2 1/2" by 3"
4, 138	21	40	.4820	63,897	25.60	13 1/2	.387	97.0	41.35	3	Angle, III of 4" by 3" by 9 lbs.
4, 139	21	37	.7580	61,752	24.80	15	.600	142.5	26.67	1	Flat, 2 1/2" by 3"
4, 139	21	37	.4261	62,784	26.17	14	.340	127.0	47.05	7	Angle, III of 3" by 2 1/2" by 8 lbs.; II of 3" by 2 1/2" by 5 lbs.
4, 140	17	54	.7812	62,084	23.00	16	.620	142.5	25.81	1	Flat, 2 1/2" by 3"
4, 140	17	54	.4329	64,193	27.64	14 1/2	.347	116.0	46.24	2	Angle, 4" by 3" by 9 lbs.; 3" by 2 1/2" by 6 lbs.
4, 168	15	.....	.7380	62,331	24.75	22	.600	142.5	26.67	1	Flat, 2 1/2" by 3"
4, 168	15	.....	.4772	62,897	25.85	14 1/2	.388	87.0	41.24	4	Angle, IV of 5" by 3" by 10 lbs.
4, 257	18	.....	.7540	63,597	28.50	22	.612	142.5	26.15	1	Flat, 2 1/2" by 3"
4, 257	18	.....	.4879	65,914	28.79	17	.390	73.0	41.08	8	Angle, III of 4" by 3" by 9 lbs.; II of 5" by 3" by 10 lbs.; d'k b'ma, III of 3" by 2 1/2" by 16 lbs.
4, 258	18	26	.7908	60,460	25.60	19	.635	142.5	25.20	1	Flat, 2 1/2" by 3"
4, 258	18	26	.5047	61,610	25.54	14	.408	87.0	39.70	4	Angle, IV of 5" by 3" by 10 lbs.
4, 260	18	.....	.7707	59,042	26.40	17 1/2	.628	142.5	25.48	2	Flat, 2 1/2" by 3"
4, 260	18	.....	.4819	62,512	26.49	14 1/2	.400	95.0	40.00	6	Angle, V of 5" by 3" by 10 lbs.; I of 2 1/2" by 2 1/2" by 5 lbs.
4, 261	15	.....	.7719	59,088	28.40	17 1/2	.620	142.5	25.81	1	Flat, 2 1/2" by 3"
4, 261	15	.....	.5054	60,947	26.15	13 1/2	.404	87.0	39.60	4	Angle, IV of 5" by 3" by 10 lbs.
4, 262	18	34	.7874	62,970	26.80	22	.635	142.5	25.20	1	Flat, 2 1/2" by 3"
4, 262	18	34	.5595	66,206	25.85	17 1/2	.441	100.5	36.28	3	Angle, II of 3" by 3" by 8 lbs.; I of 5" by 3" by 10 lbs.
4, 263	20	.....	.7874	62,220	24.50	21	.631	142.5	25.20	1	Flat, 2 1/2" by 3"
4, 263	20	.....	.4965	64,180	26.39	16 1/2	.377	81.5	42.45	6	Angle, 3 1/2" by 2 1/2" by 7 1/2" by 5 lbs.; II of 5" by 3" by 10 lbs.; d'k b'ma, II of 6" by 3 1/2" by 16 lbs.
4, 264	16	.....	.7698	60,220	28.00	19	.620	142.5	25.81	1	Flat, 2 1/2" by 3"
4, 264	16	.....	.4534	64,453	27.07	16 1/2	.359	108.0	44.57	2	Angle, II of 4" by 3" by 8 lbs.

AVERAGES.											
205	20	.....	.7625	62,164	27.00	20½	.610	142.5	26.23	1	Flat, 2½" by ¾"
4, 265	20	.....	.4397	64,729	24.77	16½	.347	117.5	46.11	5	Angle, V of ¾" by 3" by 8 lbs.; 1 of 2½" by 2½" by 5 lbs.
4, 286	14	26	.7530	60,591	27.90	16½	.600	142.5	26.67	1	Flat, 2½" by ¾"
4, 286	14	26	.4604	62,688	27.43	14½	.365	109.0	43.83	4	Angle, V of ¾" by 3" by 8 lbs.
Ratio of averages; finished shapes to test flats											
.....	17.16	39.36	.7694	61,272	26.05	19½	.6174	142.5	25.94	20	Flat, 2½" by ¾". Tested on Gill machine, Johnstown, Pa.
.....	17.16	39.36	.4741	63,631	26.05	15	.3802	102.3	42.31	75	Finished shapes. Tested on Riehle machine, Phoenixville, Pa.
Ratio of averages; finished shapes to test flats											
.....	.....	.....	.6162	1.0385	1.00	.....	.6158	.7178	1.63	.....	.....

Table IX. gives the results of tensile tests by heats at Johnstown, on material made after the instructions of October 6 were received. The average dimensions of test pieces are given, inasmuch as they are held to influence the results. Under the column headed "Elongation at maximum load" is given the stretch of the piece at the instant the beam drops with the maximum load; it is therefore a trifle greater than the extension corresponding to the highest point of the curve in a strain diagram. The corresponding stretched length was measured with an ordinary pair of dividers. The column of "Final stress in pounds per square inch of fractured area" was obtained by running down the weights while the piece was necking. This could not be done with the machine used so as to be strictly accurate for individual cases, but the average for each heat is believed to be fairly correct, except as affected by error in final area. The regularity is somewhat remarkable, the values ranging ordinarily from 100,000 to 110,000 pounds per square inch, and averaging 104,550 pounds for 31 accepted heats. Any marked defect in this quality would appear to indicate lamination or lack of uniform structure, since traces of lamination in the fracture are invariably accompanied by low values of final strength. We shall have something to say of this quality further on.

It will be observed that many of the failures towards the last are due to frequent breaks in the manufacture, the melters finding it very difficult to make a heat of soft steel of the required quality immediately after making a heat of spring steel in the same furnace.

The longest successful run is 32 heats.

TABLE IX.—Cambria steel. Tensile tests by heats.

Heat.	Carbon.	Manganese.	Average original width.	Average original thick- ness.	Sq. ins.	Average sectional area.	Average elastic limit per square inch.	Average ultimate tensile strength per square inch.	Average final elongation in 8 inches.	Average final width of original width.	Average final thickness of original thickness.	Average final area of orig- inal area.	Average time of test.	Average elongation under first stress of 80,000 pounds per square inch.	Corresponding modulus of elasticity.	Average elongation at max- imum load.	Average final stress per square inch of fractured area.	Number of tests.	Accepted or rejected.	Remarks.
4285..	.16	.....	1.236	.4388	.5423	37,760	62,147	64,149	24.53	73.39	69.98	51.82	154	.....	.....	.....	.....	4	A.	Test-plate 12 inches by 4 inch. Do. Test-plate 12 inches by 4 inch. One piece gave 20.5 per cent elongation.
4301..	.16	.....	1.239	.4308	.5336	38,869	62,461	63,874	25.25	73.50	65.06	47.73	154	.....	.....	.....	.....	4	A.	Do.
4309..	.16	.....	1.254	.3785	.4747	43,880	65,322	64,161	24.08	74.74	70.64	51.09	173	.....	.....	.....	.....	4	R.	One piece gave 20 per cent elongation.
4324..	.14	.18	1.257	.4775	.6011	49,402	63,874	64,149	24.53	73.39	69.98	51.82	163	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4325..	.14	.....	1.255	.4875	.5867	42,015	63,874	64,149	25.25	73.50	65.06	47.73	154	.....	.....	.....	.....	4	A.	Do.
4330..	.16	.....	1.247	.4048	.5798	44,798	64,937	64,161	24.08	73.39	69.98	51.82	173	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4331..	.14	.....	1.245	.4715	.5871	41,091	63,874	64,149	24.08	73.39	69.98	51.82	164	.....	.....	.....	.....	4	A.	Do.
4333..	.15	.....	1.254	.4568	.5691	44,536	63,874	64,149	24.08	73.39	69.98	51.82	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4338..	.14	.....	1.244	.4757	.5919	43,929	65,021	64,149	21.70	84.51	74.34	63.27	163	.....	.....	.....	.....	3	R.	One piece gave 20 per cent elongation.
4339..	.16	.....	1.248	.4825	.5774	40,807	65,791	65,791	23.85	78.82	73.14	57.99	17	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4340..	.13	.....	1.228	.4713	.5777	38,168	59,321	59,321	25.80	72.08	62.76	45.47	154	.....	.....	.....	.....	4	R.	One piece gave 20 per cent elongation.
4341..	.14	.....	1.256	.4580	.5734	39,395	63,144	63,144	26.50	69.26	65.57	45.03	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4343..	.15	.....	1.255	.4576	.5756	42,899	64,452	64,452	23.48	76.65	71.80	54.83	163	.....	.....	.....	.....	8	A.	One piece gave 20 per cent elongation.
4358..	.13	.....	1.246	.4415	.5499	45,233	64,161	64,161	25.93	77.34	69.41	53.27	171	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4360..	.14	.....	1.247	.4293	.5355	43,749	60,632	60,632	27.15	72.84	64.45	48.91	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4366..	.17	.....	1.251	.4330	.5416	43,894	60,095	60,095	24.88	74.15	70.24	52.05	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4367..	.18	.....	1.282	.4380	.5559	43,156	65,598	65,598	24.73	72.05	68.50	49.05	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4421..	.20	.....	1.258	.4365	.5491	45,440	69,436	69,436	24.48	74.32	69.87	51.95	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4422..	.21	.....	1.272	.4295	.5373	47,218	69,798	69,798	23.38	76.39	64.10	47.27	17	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4427..	.15	.....	1.256	.4290	.5388	45,093	65,232	65,232	23.80	73.84	64.10	47.27	17	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4428..	.18	.....	1.271	.4433	.5610	44,745	67,796	67,796	22.90	73.89	69.51	51.60	19	.....	.....	.....	.....	3	R.	One piece gave 20 per cent elongation.
4430..	.17	.....	1.258	.4380	.5509	42,445	65,299	65,299	25.88	73.92	69.53	51.39	17	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4431..	.20	.....	1.267	.4388	.5519	44,930	68,290	68,290	23.90	77.57	73.12	57.30	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4432..	.16	.....	1.251	.4328	.5412	41,119	65,597	65,597	24.23	76.27	72.58	51.55	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4433..	.15	.79	1.238	.4318	.5397	42,010	62,065	62,065	24.80	76.01	72.18	54.17	16	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4434..	.12	.81	1.236	.4378	.5594	38,358	61,848	61,848	23.03	73.72	68.13	51.00	164	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.
4435..	.15	.....	1.240	.4500	.5586	43,116	65,049	65,049	25.40	75.09	69.72	52.25	173	.....	.....	.....	.....	4	A.	One piece gave 20 per cent elongation.

TABLE IX.—Cambria steel. Tensile tests by heats—Continued.

Heat.	Carbon.	Manganese.	Average original width.	Average original thickness.	Average sectional area.	Average elastic limit per square inch.	Average ultimate tensile strength per square inch.	Average final elongation in 8 inches.	Average final width of original width.	Average final thickness of original thickness.	Average final area of original area.	Average time of test.	Average elongation under first stress of 30,000 pounds per square inch.	Corresponding modulus of elasticity.	Average elongation at maximum load.	Average final stress per square inch of fractured area.	Number of tests.	Accepted or rejected.	Remarks.
4436.	.12	.42	1.251	.4448	5549	41,820	64,251	25.95	74.24	67.45	50.10	184	4	A.	One piece broke through a flaw, with only 21.6 per cent elongation.
4437.	.17	.34	1.248	.4458	5564	38,753	60,603	26.75	70.70	65.81	46.47	18	.....	.....	.....	.....	4	A.
4438.	.18	.26	1.235	.4488	5542	41,761	65,260	25.95	76.01	70.75	53.97	174	.....	.....	.....	.....	4	A.
4439.	.16	.....	1.253	.4435	5565	40,832	62,638	26.80	74.11	68.32	50.65	174	.....	.....	.....	.....	4	A.
4441.	.12	.....	1.250	.4375	5489	42,692	61,577	23.95	75.20	67.70	51.20	164	.....	.....	.....	.....	4	A.
4445.	.18	.....	1.239	.4450	5513	42,363	66,936	23.53	78.09	73.77	57.65	184	.....	.....	.....	.....	4	A.
4447.	.14	.54	1.239	.4350	5389	41,203	66,367	25.65	76.89	70.97	54.05	18	.....	.....	.....	.....	4	A.
4449.	.16	.42	1.239	.4500	5636	38,176	61,229	27.13	72.64	68.67	49.90	17	.....	.....	.....	.....	4	A.
4450.	.11	.49	1.248	.4400	5489	43,135	62,091	26.23	73.64	63.72	46.90	164	.....	.....	.....	.....	4	A.
4452.	.18	.64	1.244	.4300	5318	45,399	70,460	24.15	75.73	71.54	54.91	194	.....	.....	.....	.....	8	A.
4453.	.17	.37	1.244	.4500	5597	41,600	64,320	24.23	73.76	69.62	51.40	154	.....	.....	.....	.....	4	A.
4454.	.14	.29	1.241	.4400	5461	40,477	62,307	26.63	73.21	68.93	50.50	15	.....	.....	.....	.....	4	A.
4457.	.16	.....	1.245	.4400	5478	45,880	67,234	26.10	74.49	70.03	52.07	164	.....	.....	.....	.....	4	A.
4458.	.16	.....	1.243	.4350	5467	43,750	66,045	25.90	73.84	69.69	51.45	17	.....	.....	.....	.....	4	A.
4459.	.15	.44	1.240	.4400	5394	45,094	65,230	26.23	72.17	68.78	49.35	174	.....	.....	.....	.....	4	A.
4460.	.16	.....	1.235	.4375	5403	45,850	66,098	25.90	70.34	60.39	42.52	174	.....	.....	.....	.....	4	A.
4461.	.16	.....	1.240	.4325	5363	43,594	66,824	24.78	73.99	71.58	52.82	174	.....	.....	.....	.....	4	A.
4462.	.17	.53	1.243	.4300	5343	43,375	64,964	27.43	72.43	68.86	49.38	174	.....	.....	.....	.....	4	A.
4463.	.13	.....	1.240	.4450	5518	39,989	62,607	27.85	71.58	64.50	46.15	164	.....	.....	.....	.....	4	A.
4464.	.15	.....	1.240	.4450	5518	39,989	62,607	27.85	71.58	64.50	46.15	164	.....	.....	.....	.....	4	A.
4465.	.12	.....	1.245	.4300	5353	39,797	60,576	25.96	73.98	67.37	49.97	15	.....	.....	.....	.....	8	A.
4466.	.16	.....	1.240	.4425	5487	38,154	62,621	27.00	69.75	63.93	44.62	144	.....	.....	.....	.....	4	A.
4468.	.....	.....	1.240	.4400	5456	39,925	64,539	25.78	70.66	64.58	45.60	184	.....	.....	.....	.....	4	A.
4470.	.18	.....	1.237	.4400	5445	38,117	63,562	25.95	71.00	62.40	44.30	154	.....	.....	.....	.....	4	A.
4478.	.....	.....	1.246	.4300	5358	40,542	60,389	26.40	74.76	67.80	50.72	15	.....	.....	.....	.....	8	A.
4501.	.14	.....	1.250	.4300	5375	42,837	66,047	26.50	75.60	68.92	52.05	174	.....	.....	.....	.....	4	A.
4503.	.16	.....	1.235	.4300	4940	50,000	69,230	26.00	86.63	80.25	69.50	20	.....	.....	.....	.....	1	A.
4504.	.18	.....	1.235	.4125	5085	46,339	88,420	24.20	77.73	73.38	56.77	184	.....	.....	.....	.....	4	A.
4505.	.18	.....	1.236	.4175	5161	47,451	88,763	23.90	80.89	76.48	61.85	18	.....	.....	.....	.....	4	A.
4507.	.17	.....	1.237	.4400	5531	39,012	61,339	26.23	74.48	72.98	54.37	154	.....	.....	.....	.....	4	A.
4508.	.13	.....	1.235	.4400	5522	37,307	67,306	25.90	69.32	64.19	44.49	15	.....	.....	.....	.....	1	A.

4817...	20	1.265	4400	5666	48,178	65,761	28.98	76.28	71.22	54.42	17	1	A.	One piece gave 21 per cent. elongation.
4845...	15	1.250	4396	5375	40,674	62,721	28.03	70.00	68.38	47.86	16	4	A.	
4846...	18	1.250	4400	5500	42,693	68,808	28.63	74.60	72.91	54.75	18	4	A.	
4847...	16	1.250	4400	5500	42,091	68,786	28.63	73.60	69.88	51.35	16	4	A.	
4848...	20	1.250	4400	5500	40,481	62,886	28.43	72.00	65.90	48.55	16	4	A.	
4850...	15	1.255	4350	5450	43,490	63,774	24.45	75.69	69.34	52.52	17	4	A.	
4851...	20	1.250	4400	5400	40,792	67,002	24.68	75.87	69.12	52.32	18	4	A.	
4852...	17	1.249	4400	5500	40,499	63,273	26.70	73.60	67.04	49.45	13	4	A.	
4853...	19	1.250	4400	5500	40,999	64,567	26.70	73.60	69.12	51.32	16	4	A.	
4858...	19	1.245	4375	5198	46,065	65,244	24.45	73.60	69.12	51.32	16	4	A.	
4861...	16	1.245	4375	5447	41,215	63,262	23.00	76.72	68.09	51.45	15	4	A.	
4862...	14	1.258	4200	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4874...	14	1.252	4200	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4878...	16	1.252	4200	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4881...	16	1.252	4200	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4882...	17	1.252	4200	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4884...	12	1.257	4235	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4886...	14	1.257	4235	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4890...	16	1.257	4235	5281	45,561	63,708	23.70	74.95	68.68	51.45	17	4	A.	
4708...	15	1.262	4542	5274	38,890	60,605	26.58	75.4	67.02	50.42	15	4	A.	One piece broke through flaw, with only 20 per cent. elongation.
4711...	11	1.259	4510	5678	39,765	60,998	25.48	76.16	72.00	54.87	14	4	A.	
4712...	23	1.256	4439	5578	46,768	70,824	23.46	78.70	76.86	60.57	20	8	A.	
4713...	15	1.259	4648	5851	40,040	62,560	23.98	77.63	74.06	57.72	15	4	A.	
4715...	15	1.001	4350	4854	42,095	63,690	23.03	72.94	67.52	49.27	16	4	A.	
4716...	14	1.261	4265	5379	40,845	63,533	26.93	74.24	73.21	54.40	17	4	A.	
4717...	14	1.261	4265	5379	40,845	63,533	26.93	74.24	73.21	54.40	17	4	A.	
4718...	14	1.261	4265	5379	40,845	63,533	26.93	74.24	73.21	54.40	17	4	A.	
4719...	13	1.268	4417	5585	43,470	65,418	25.15	76.54	69.81	53.47	17	4	A.	
4720...	13	1.268	4417	5585	43,470	65,418	25.15	76.54	69.81	53.47	17	4	A.	
4721...	13	1.268	4417	5585	43,470	65,418	25.15	76.54	69.81	53.47	17	4	A.	
4722...	18	1.240	4360	5694	42,800	64,890	20.50	78.06	76.53	59.70	19	4	R.	
4723...	19	1.240	4360	5694	42,800	64,890	20.50	78.06	76.53	59.70	19	4	R.	
4724...	24	1.240	4360	5694	42,800	64,890	20.50	78.06	76.53	59.70	19	4	R.	
4725...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4726...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4727...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4728...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4729...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4730...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4731...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4732...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4733...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4734...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4735...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4736...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4737...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4738...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4739...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4740...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4741...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4742...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4743...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4744...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4745...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4746...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4747...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4748...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4749...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4750...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4751...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4752...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4753...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4754...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4755...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4756...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4757...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4758...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4759...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4760...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4761...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4762...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4763...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4764...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4765...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4766...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4767...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4768...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4769...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4770...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4771...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4772...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4773...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4774...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4775...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4776...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4777...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4778...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4779...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4780...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4781...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4782...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	52.50	16	4	A.	
4783...	19	1.260	4438	5751	44,375	64,608	25.70	76.18	68.90	5				

TABLE IX.—Cambria steel. Tensile tests by heats—Continued.

Heat.	Carbon.	Manganese.	Average original width.	Average original thickness.	Average sectional area.	Average elastic limit per square inch.	Average ultimate tensile strength per square inch.	Average final elongation in 8 inches.	Average final width of original thickness.	Average final thickness of original thickness.	Average final area of original area.	Average time of test.	Average elongation under first stress of 30,000 pounds per square inch.	Corresponding modulus of elasticity.	Average elongation at maximum load.	Average final stress per square inch of fractured area.	Number of tests.	Remarks.
4877.	.16	...	1.255	.4200	5384	40,885	65,685	Per ct. 26.15	Per ct. 75.00	Per ct. 70.16	Per ct. 52.75	184	.008725	27,510,000	19.43	108,275	4	Accepted or rejected.
4878.	.15	...	1.254	.4240	5443	39,840	63,360	25.93	74.28	71.36	52.97	118	.00861	27,875,000	21.53	108,475	4	One piece gave 20.7 per cent. elongation.
4881.	.14	...	1.255	.4328	5431	38,088	61,540	25.58	73.00	69.02	50.42	117	.008625	27,830,000	19.68	105,400	4	
4904.	.15	...	1.246	.4355	5650	44,343	68,095	23.18	77.68	74.85	58.12	171	.00884	27,150,000	20.20	111,000	4	
4905.	.14	.40	1.249	.4378	5683	37,075	61,713	26.28	70.72	65.45	48.30	153	.00884	27,150,000	20.20	111,000	4	
4907.	.16	...	1.254	.4383	5596	41,035	64,923	24.38	77.35	71.72	55.50	164	.00840	28,370,000	18.32	104,825	4	
4908.	.14	...	1.252	.4180	5206	39,615	62,568	28.53	73.47	68.80	50.57	164	.00840	28,370,000	18.32	104,825	4	
4917.	.13	.43	1.245	.4190	5304	41,520	62,070	20.70	59.16	66.96	50.50	164	.00810	28,610,000	18.32	104,825	4	
4918.	.14	...	1.244	.4372	5423	38,080	62,818	25.43	76.32	72.41	55.42	119	.00869	27,820,000	20.23	104,150	4	
4919.	.14	...	1.245	.4450	5520	40,890	64,098	24.08	76.32	72.41	55.42	119	.00869	27,820,000	20.23	104,150	4	
4920.	.14	...	1.245	.4380	5417	38,875	62,380	27.80	71.46	64.55	48.15	173	.00835	27,820,000	20.23	104,150	4	
4921.	.15	...	1.247	.4367	5382	38,875	62,380	27.80	71.46	64.55	48.15	173	.00835	27,820,000	20.23	104,150	4	
4922.	.15	...	1.247	.4367	5382	38,875	62,380	27.80	71.46	64.55	48.15	173	.00835	27,820,000	20.23	104,150	4	
4923.	.16	...	1.254	.4220	5380	41,253	63,375	24.13	73.37	68.34	48.17	173	.00825	27,820,000	20.23	104,150	4	
4934.	.17	.48	1.256	.4405	5531	41,023	63,368	23.78	73.10	64.85	50.00	194	.007825	31,475,000	18.00	98,300	4	One piece gave 20.3 per cent. elongation.
4951.	.16	...	1.256	.4405	5531	41,023	63,368	23.78	73.10	64.85	50.00	194	.007825	31,475,000	18.00	98,300	4	
4952.	.14	...	1.251	.4413	5518	42,473	64,778	23.00	77.06	73.39	58.09	154	.00828	27,550,000	18.95	100,806	4	
4953.	.17	...	1.247	.4418	5506	42,473	64,778	23.00	77.06	73.39	58.09	154	.00828	27,550,000	18.95	100,806	4	
4981.	.14	...	1.247	.4467	5506	37,598	59,451	27.89	76.81	68.71	48.69	154	.00871	27,550,000	18.13	101,018	4	
4983.	.14	...	1.252	.4410	5520	37,725	61,481	23.55	78.19	71.47	48.69	154	.00871	27,550,000	18.13	101,018	4	
4984.	.15	...	1.252	.4427	5520	37,725	61,481	23.55	78.19	71.47	48.69	154	.00871	27,550,000	18.13	101,018	4	
5003.	.18	...	1.248	.4285	5539	38,783	61,015	26.03	73.46	68.62	53.22	164	.00865	27,120,000	20.23	104,445	4	
5015.	.15	...	1.269	.4453	5610	40,373	63,545	25.20	74.34	68.62	53.22	164	.00874	27,450,000	20.75	108,675	4	
5016.	.14	...	1.264	.4443	5640	39,045	62,440	27.03	74.22	68.37	48.92	164	.00874	27,450,000	20.75	108,675	4	
5216.	.17	...	1.254	.4522	5670	40,269	61,778	24.88	74.65	67.80	56.47	164	.008775	27,350,000	20.25	108,900	4	
5219.	.14	...	1.261	.4468	5670	37,631	61,267	23.25	73.04	65.56	48.23	164	.00826	29,055,000	20.25	108,900	4	
5220.	.16	...	1.268	.4565	5788	35,793	63,912	25.04	73.04	65.56	48.23	164	.00826	29,055,000	20.25	108,900	4	
5221.	.15	.49	1.260	.4423	5678	38,176	62,608	23.54	73.04	65.56	48.23	164	.00910	26,370,000	20.25	108,900	4	
5253.	.18	...	1.251	.4378	5476	39,162	60,756	24.48	76.23	68.95	52.38	164	.00885	26,370,000	20.25	108,900	4	
5255.	.14	...	1.248	.4403	5507	40,442	62,279	26.08	73.74	68.52	50.45	164	.00820	26,370,000	20.25	108,900	4	

* Mean of three pieces.

The following general summary gives in brief the results of the physical tests of the Cambria open-hearth steel supplied:

Summary of tensile tests. Cambria open-hearth steel.

[NOTE.—Tensile tests by heats were made from 6-inch by $\frac{1}{2}$ -inch flat on Gill screw machine, at Cambria Iron Works, Johnstown, Pa. Tensile tests on finished material were made on Richlé hydraulic machine at Phoenix Iron Works, Phoenixville, Pa.]

	Tensile tests by heats.				Tensile tests on finished accepted material.	Tensile tests on all accepted material.
	Accepted material.	Material rejected for lack of ductility.	Material rejected for lack of strength.	Material rejected on quenching test.		
Number of heats	114	10	6	3	19	133
Number of tests	483	21	22	12	91	574
Average carbon in per cent.	a .1605	.162	.1333	.1666	.1716	.1622
Average original width of cross-section	1.248	1.248	1.252	1.253	1.250	1.249
Average original thickness of cross-section .....	.4539	.4322	.4446	.4390	.3724	.4423
Average original area of cross-section .....	.5624	.5396	.5566	.5519	.4637	.5483
Average elastic limit in pounds per square inch	41,440	44,133	36,796	639,153	639,450	641,247
Average ultimate tensile strength in pounds per square inch	64,057	65,871	58,284	62,640	63,800	64,020
Average elongation in 8 inches in per cent.	25.42	21.91	27.11	26.02	26.11	25.52
Average final width in per cent. of original width	e75.04	80.09	70.72	b74.47	73.14	f74.76
Average final thickness in per cent. of original thickness	e69.88	73.97	65.37	b68.51	66.97	f69.46
Average final area in per cent. of original area	52.85	60.36	46.35	53.62	49.12	52.32
Least modulus of elasticity	24,680,000	24,360,000	25,920,000	26,000,000	.....	24,680,000
Greatest modulus of elasticity	30,890,000	31,475,000	27,060,000	27,120,000	.....	30,890,000
Average modulus of elasticity	g27,720,000	A28,091,000	b26,490,000	b26,560,000	.....	g27,720,000
Average elongation at maximum load	i20.17	j18.85	k22.24	b20.94	.....	i20.17
Average final strength in pounds per square inch of fractured area	l104,550	j98,402	k101,018	b106,459	.....	l104,550
Average time of test in minutes.	m17 $\frac{1}{2}$	17 $\frac{1}{2}$	15 $\frac{1}{2}$	b16 $\frac{1}{2}$	15	n17

a For 109 heats.
b For 2 heats.
c For 10 heats.
d For 124 heats.

e For 113 heats.
f For 132 heats.
g For 42 heats.
h For 5 heats.

i For 25 heats.
j For 4 heats.
k For 1 heat.
l For 31 heats.

m For 107 heats.
n For 126 heats.

SUMMARY OF TESTS AND INSPECTION.

The following general summary gives the principal particulars of tests and inspection in the aggregate. It is seen that out of 880 heats tested up to 1st September, 1884, only 146, or 16.6 per cent., were rejected, and this amount would have been further diminished if the orders for boiler steel could have been issued sooner, notably in the case of the Norway steel, many heats of which, too soft for ship metal, passed satisfactory tests for boiler metal, but were rejected for lack of orders. The very small amount of material rejected on the quenching test, after being accepted by heat tests, is still sufficient to call attention to the efficiency of this test; increasing familiarity of manufacturers with the requirements and method of tests would still further diminish the amount so rejected. The necessity for this test, nevertheless, exists in that it is applied to each piece and prevents all possibility of serious defect arising from treatment subsequent to casting or of mistake at works producing many grades of steel.

General summary of results for all steel plates and bars delivered up to September 1, 1884.

Manufacture of steel.	Weight in tons delivered up to September 1, 1884.		Average ultimate tensile strength per square inch.	Average final elongation.	Efficiency number.*	Energy required to break a bar 1sq. inch sect. area and 8 inches long between fillets.†	Weight in tons rejected on quenching test.	Number of heats accepted.	Number of heats rejected on tensile test.	Percentage rejected of total number of heats tested.	Amount rejected on quenching test in per cent. of total amount delivered.
	Tons.	Pounds.	Per cent.			Fr. lbs.	Tons.			Per cent.	Per cent.
Chester Rolling Mills.	1,616.17	61,987	26.09	1,617,141	9,698	14.73	237	60	20.20	0.91	
Park, Bro. & Co.	287.40	63,125	25.83	1,630,519	9,788	23.93	56	9	13.84	8.83	
Norway Steel and Iron Co.	1,616.22	62,472	25.56	1,596,784	9,581	13.75	308	61	16.53	0.85	
Cambria Iron Co.	1,053.00	64,020	25.52	1,638,790	9,803	3.41	133	16	10.74	0.32	
Total	4,572.79					55.82	734	146			
Average		62,698	25.755	1,619,560	9,685				16.59	1.22	

* Efficiency number = ultimate tensile strength \times final elongation. See p. 515.

† On a basis of area of strain diagram = 0.9 of efficiency number. See p. 516.

Results for both tensile strength and ductility are necessary for an estimate of absolute quality of metal as distinguished from mere hardness or softness. Either result may be altered only by corresponding alteration of the other in material of given intrinsic quality; and, as extreme cases, if both be high the steel is good, if both be low the steel is poor. A single measure of intrinsic quality is available in the "ultimate resilience" or amount of work necessary to produce rupture of a piece of standard dimensions. An accurate value of this function can only be obtained from a strain diagram, which denotes the power of resistance of the material, as an indicator-card gives the power of overcoming resistance for an engine, and is equally a gauge of quality under standard conditions. Without automatic apparatus for describing them, a strain diagram is not to be obtained for each piece, but analysis of the diagrams made during this inspection (pp. 149 and 150) shows that, for unannealed material such as we are considering, in no particularly abnormal physical condition, the area of the strain diagram bears a pretty constant ratio to the product of its extreme dimensions, and may be taken as not far from 90 per cent. of the product of ultimate tensile strength and final elongation. The latter product, therefore, may be considered a more or less accurate measure of intrinsic quality for pieces of standard dimensions, and is called in the table the efficiency number.

While the measured length in all tests was the same (8 inches), the area and proportion of cross-section varied widely except in tests made at the Cambria Iron Works; so that, as the proportion of the test piece is held to affect the results for ductility, a comparison of the efficiency numbers in the table cannot be taken as a strict gauge of relative quality. The average sectional area of all tests is not far from .5 square inch, for which dimensions the average efficiency number is seen to be 1,619,560, in pounds per cent. Taking the area of strain diagram as 90 per cent. of the efficiency number in pounds per cent., and reducing to foot-pounds, we have 9,685 foot-pounds as the average ultimate resilience of a bar of one square inch sectional area 8 inches long, the ductility being reckoned on the basis of one-half a square inch of sectional area.

The above value of the efficiency number being for material accepted, and therefore of good quality, we see that, under these conditions of test, the minimum strength required for boiler plate, 57,000 pounds,

should be accompanied by a ductility of 28.4 per cent.; while the material of the maximum strength allowed, 63,000 pounds, should have 25.7 per cent. elongation. For ship material, 60,000 pounds should be accompanied by 27 per cent. elongation, while the minimum elongation of 23 per cent. should be associated with a tensile strength of 70,400 pounds. A good guide in fixing specifications is thus obtained, and the margin allowed manufacturers under any given specification can be appreciated.

For purposes of comparison with foreign results or specifications, the average results may be stated as a tensile strength of 62,698 pounds, or 28 tons, per square inch (= 44.09 kilograms per square millimeter) with a ductility in 8 inches of 25.755 per cent. on an area of one-half square inch.

STEEL IN THE SHIP-YARD AND BOILER-SHOP.

Of the total of 4,570 tons delivered, about 4,000 tons had been worked into hull and boilers by September 1, 1884. In the boiler-shops a certain amount of experience had already been obtained in treating the material. Although previously using steel for certain parts of boilers, the contractors, Messrs. John Roach & Son, had commenced constructing boilers entirely of steel (of somewhat softer quality than that for the cruisers) in 1882, using not far from 1,000 tons each in that and the next year.

In the ship-yard the workmen had little or no experience with the material. Yet the results obtained in point of failures of material under treatment in the ship-yard are particularly good. The bending of frames and all joggling were done hot; welding of beam-arms, and in most other places, was done with glut-pieces of iron between the steel surfaces, though the staple-angles in the wings of the double bottom were welded steel to steel. Boss-plates were shaped hot, without accident. But four failures were reported, and of these the cause was evident, as given in the table.

TABLE X.—*Failures of steel in working up to September 1, 1884.*

Date.	To be employed for—	Treatment when failure occurred.	Cause assigned.	Makers.
December 17, 1883.	Tube-sheet, Atlanta's boilers.	Being chipped hot near punched edge.	.....	Chester Rolling Mills.
December 18, 1883.	Boss-frame, Dolphin...	Fairing by hydraulic fairing-machine.	Overheating ..	Phoenix Iron Company.
January 12, 1884 ...	...do .....	...do .....	...do	Do.
January 31, 1884 ...	2 shell-plates, Boston's boilers.	Cracked from outer row of rivet-holes to edge of plate.	.....	Chester Rolling Mills.
February 23, 1884.	Front head, Boston's boilers.	Cracked from edge while flanging.	.....	Do.
March 14, 1884	Back head, Atlanta's boilers.	Cracked from edge after riveting up.	.....	Do.
March 24, 1884	2 tube-sheets, Chicago's boilers.	Flanging	Laminations ..	Norway Steel and Iron Company.
March 27, 1884 ...	Back tube-sheet, Chicago's boilers.	.....do .....	...do	Do.
April 16, 1884	3 back tube-sheets, Chicago's boilers.	Developed laminations in flanging.	...do	Do.
April 16, 1884	1 back tube-sheet, Chicago's boilers.	Developed laminations in flanging, and cracked from edge partially flanged.	.....	Do.
May 10, 1884.	2 superstructure beams, Atlanta and Boston.	Setting knee to shape.	Web out too deep in removing bulb to lay.	Phoenix Iron Company.

The chief source of trouble was in flanging the boiler-plates, failure frequently occurring from laminations in the edge of the plate. Some of the more or less unaccountable failures after treatment arising from a state of internal strain will be found.

It should be stated that the rivet-holes were punched in the boiler-plates of the Dolphin, Boston, and Atlanta, and drilled in those of the Chicago.

The first failure, reported December 17, 1883, is thus described by the inspector:

"The sheet had been partially flanged and punched for tube-hole cutter-guide; while cutting off a piece, marked A, hot, with a chisel, the sheet split $1\frac{1}{2}$ inches; while cooling the crack extended $4\frac{1}{2}$ inches, and when cold, as the sheet was being hauled over the ground, the crack extended 5 inches farther.

"The number of the sheet had been obliterated. Since the failure of that sheet, seven others have been subjected to the same punching, cutting, and flanging, and no failures have occurred."

A strip $1\frac{1}{2}$ inches wide was sheared from that portion which had been punched out by the lines of holes marked B and C in the diagram; it broke easily on bending, but after heating and quenching in water, it bent double under a sledge without fracture.

From each of the two steel plates of the Boston's boilers reported January 31, 1884, two pieces for tensile test were cut, as near as possible to the rivet-holes, and gave the following average results, with trifling variations for individual pieces: 59,275 pounds tensile strength, with 25.58 per cent. elongation, and a final area of 47.6 per cent.; perfectly consistent and normal, though the efficiency number is not particularly high and considerably lower than for the corresponding heat tests.

The heat test of the sheet reported February 23, 1884, gave 30.84 per cent. elongation, with a final area of 48.5 per cent., being heat No. 582 in the tables of Chester steel.

The total weight of material contained in the table of failures is less than 17,500 pounds, or about $7\frac{3}{4}$ tons, a very small per cent. of the amount delivered.

STEEL FOR RIVETS.

A built-up structure, such as ship or boiler, depends for strength almost entirely upon the resistance offered at the joints, which resistance, for most conditions of stress, is, or should be, made up equally of the resistances of plate and of rivet. When, in addition, we consider the severe treatment and liability to excessive internal strain to which a rivet is subjected in driving and setting, the necessity for careful selection of material and of quality is very apparent. There are two chief opposing conditions in the selection of rivet-metal, the one the great advantage gained in increased strength of joint by using metal of higher shearing strength with fewer or smaller rivets, the other the brittleness of heads and shanks of rivets developed in hard metal under severe treatment. It is a matter for careful consideration whether the first cannot be obtained in a higher degree than at present without too great development of the second.

The rivets supplied were all of steel made by the Bessemer process, chiefly by the Pittsburgh Steel Casting Company, though a few thousand pounds were made by the Burden Iron Company, Troy, N. Y. The steel supplied by the above company was delivered in billets, marked with the number of the blow, to the rivet manufacturers, each

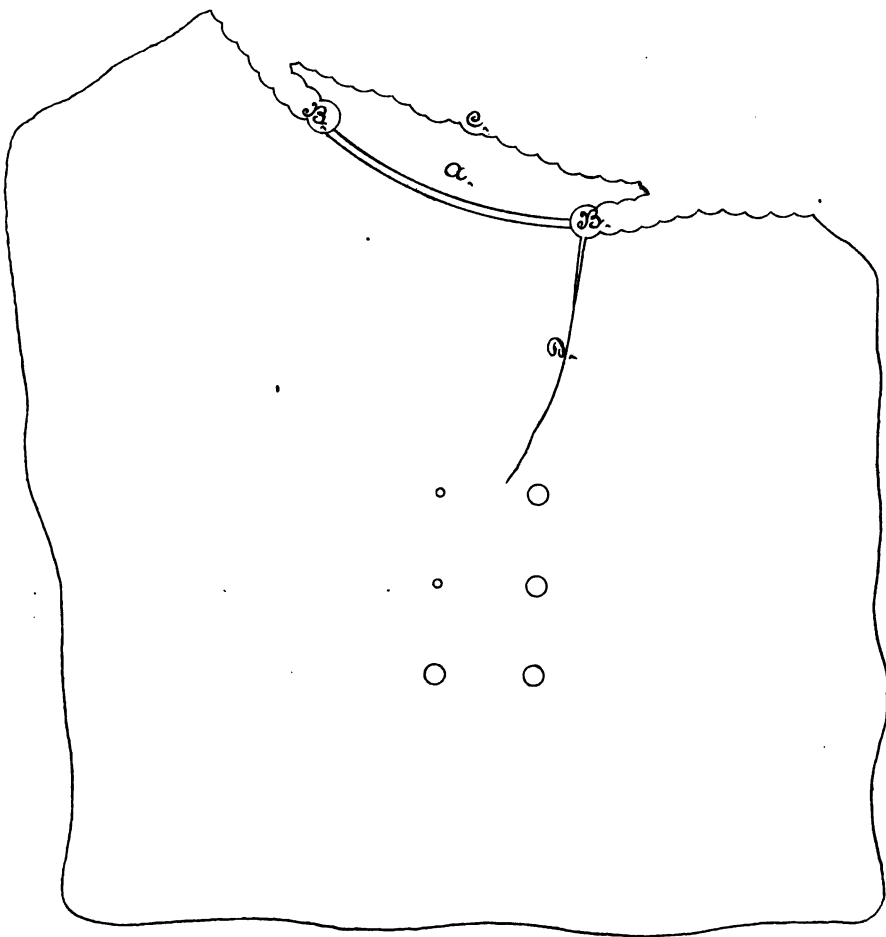


Fig. 9 -Illustrating failure of tube sheet of "Atlanta's" boilers.





HAMMER AND TENSILE TEST PIECES $\frac{3}{4}$ " RIVETS.



HAMMER AND SHEAR TEST SPECIMENS $\frac{3}{4}$ " RIVETS.



HAMMER TEST SPECIMENS $\frac{3}{4}$ " RIVETS.

A. Hoen & Co. Stationers & Printers, Baltimore.

blow rolling out into about 200 rivet-bars. The rivets first used were made by Jones & Laughlin, of Pittsburgh, Pa., of the steel mentioned, and the same metal was subsequently used at the Combination Steel and Iron Works, Lamokin, Pa., which later undertook the whole supply.

The high tensile strength, which from the first tests appeared necessary to obtain the shearing strength of 50,000 pounds per square inch demanded, was looked upon with some alarm for fear of trouble arising from brittle heads as reported in European practice. Somewhat less shearing strength was therefore allowed if accompanied by correspondingly lower tensile strength and greater ductility and reduction of area. The necessity for this, however, soon disappeared, the results of tests being quite up to the original requirements, while the high ductility and the especially high reduction of area showed a metal capable of great local distortion without fracture.

The amount of testing was then reduced, and instead of 20 rivet-bars constituting a lot for tensile test and 500 pounds of rivets a lot for shearing and hammer tests, 2 bars of sufficient length for tensile test were required to accompany each 1,000 pounds of rivets, being pieces of the bars from which the rivets in the correspondingly-marked kegs were made, and one test of each kind was made for each 1,000 pounds of rivets delivered at the works. As has been mentioned, also, the shearing specimens were riveted up in single shear instead of double shear, increasing the representative value of the test. The value of the shearing strength in single shear is somewhat greater with iron rivets in iron plates than in double shear in a variable ratio, approximately 10 to 9.5. The invariably low ratios of shearing to tensile strengths for the double-shear specimens of lots 9, 13, 33, and 40, in the table, appear to show a similar effect in steel rivets, though the single shear specimens of lot 33 show even a lower ratio than the double shear. It is, however, very difficult to obtain simultaneous shear of the two sides in a double-shear specimen.

Steel plates of ship or boiler quality and of thicknesses suitable to the length of the rivet were used in the shearing specimens.

The Board is particularly pleased with the uniformity and high value of shearing strength obtained, as associated, also, with a high value of those qualities which go to make a rivet work well and safely, and great credit is due the original manufacturers of the steel in producing a quality of metal so especially well adapted to this important purpose.

Tests and inspection of rivets.—The rivets, from whatever source, were generally tested at Chester by the inspectors at the Chester Rolling Mills, the shearing specimens being riveted up at the ship-yard. Table XI. gives a record of tests by lots, and includes a general summary of the various sizes, and in total, up to September 20, 1884. The amount rejected, 14,100 pounds, 10,000 pounds of which were rejected in the early part of the work, is only 3.87 per cent. of the total amount tested, and the results depart but little from specification. The ratio of shearing to tensile strength is given for each lot in the table, and its average value for each size, as shown by the summary, illustrates well the increase for smaller rivets.

The capacity for local distortion, as shown by the low value of the percentage of final area, is more markedly illustrated by the opposite photograph of specimens of hammer test pieces, which are not selected for their particular excellence, as these tests were invariably passed in the most satisfactory manner. The fracture of the tensile test piece illustrates that commonly obtained from this material.

TABLE XI.—Tests of rivets and rivet bars. *Chester Rolling Mills.*

Lot No.	Tensile tests.						Shearing tests.						Accepted or rejected.	Manufacturer.	Remarks.			
	Nominal size of rivet.	Average original diameter.	Average original area.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Passed or failed.	Nominal size of rivet hole.	Average shearing area.	Average ultimate shearing strength per square inch.	Ratio to tensile strength.				Number of tests.	Passed or failed.	Hammer and bending tests passed or failed.
9	Inch.	Sq. in.	Pounds	Per cent.	Per cent.		4	P.	Inch.	Sq. in.	Pounds	Per cent.	10	P.	P.	Double shear. Double shear. Single shear.		
13	.693	.3773	60,050	26.78	41.6		2	P.	1 1/8	1.037	47,495	79.10	2	P.	P.	Do.		
14	.764	.4584	70,120	24.10	53.7				1 1/8	1.380	56,100	80.00	2	P.	P.	Double shear.		
33	.694	.3782	60,375	26.48	44.2		4	P.	1 1/8	.5185	55,917	73.64	6	P.	P.	Do.		
40	.720	.4071	57,263	28.50	41.8		4	P.	1 1/8	1.037	44,467	76.94	6	P.	P.	Do.		
40	.820	.5281	66,950	27.15	43.0		2	P.	1 1/8	.5185	46,450	76.94	3	P.	P.	Double shear.		
43	.844	.5592	61,800	30.30	42.8		2	P.	1 1/8	1.380	52,900	79.02	2	P.	P.	Do.		
46	.595	.2780	65,890	24.85	38.0		2	P.	1 1/8	.6903	54,400	88.03	2	P.	P.	Combination Iron and Steel Works.		
47	.702	.3870	63,400	30.70	32.9		2	P.	1 1/8	.3712	55,633	84.44	3	P.	P.	Do.		
52	.700	.3850	62,650	29.95	32.9		2	P.	1 1/8	.5185	54,900	86.60	3	P.	P.	Do.		
53	.709	.3960	61,290	27.82	44.4		6	P.	1 1/8	.5180	55,980	90.68	5	P.	P.	Do.		
54	.699	.3847	62,160	27.48	37.3		5	P.	1 1/8	.5180	49,540	76.70	10	P.	P.	Do.		
56	.721	.4072	59,000	27.60	36.0		1	P.	1 1/8	.5180	52,000	88.14	1	P.	P.	Do.		
66	.593	.2760	63,740	25.07	40.5		3	P.	1 1/8	.3710	56,140	88.96	5	P.	P.	Do.		
69	.698	.3829	60,740	27.55	42.0		10	P.	1 1/8	.5165	54,920	90.42	10	P.	P.	Do.		
110	.692	.3740	63,012	28.32	43.4		17	P.	1 1/8	.4277	50,712	80.50	17	P.	P.	Do.		
111	.749	.4402	60,395	30.23	40.9		30	P.	1 1/8	.5184	52,790	87.20	30	P.	P.	Do.		
112	.875	.6013	59,895	28.38	42.8		4	P.	1 1/8	.6900	52,167	87.20	3	P.	P.	Do.		
125	.747	.4383	61,814	27.93	39.7		7	P.	1 1/8	.5656	56,143	90.84	7	P.	P.	Do.		
128	.748	.4387	62,183	26.17	40.5		6	P.	1 1/8	.5184	57,714	92.83	7	P.	P.	Do.		
129	.750	.4410	69,600	28.66	43.6		5	P.	1 1/8	.5350	55,200	79.31	5	P.	P.	Do.		
130	.749	.4402	69,667	27.90	47.7		6	P.	1 1/8	.5460	57,667	82.78	6	P.	P.	Do.		
137	.744	.4343	70,250	28.30	44.2		8	P.	1 1/8	.5160	53,675	76.41	8	P.	P.	Do.		
138	.746	.4368	61,917	28.75	36.8		6	P.	1 1/8	.5053	53,500	86.42	6	P.	P.	Do.		
145	.755	.4480	60,000	28.00	43.0		1	P.	1 1/8	.5180	53,000	88.33	1	P.	P.	Do.		
170	.625	.3070	61,000	27.17	40.0		3	P.	1 1/8	.3710	54,833	88.24	3	P.	P.	Do.		
176	.760	.4540	63,500	28.00	40.0		2	P.	1 1/8	.5180	50,000	78.74	2	P.	P.	Do.		
171	.634	.3160	61,000	25.50	40.5		2	P.	1 1/8	.3710	54,000	88.53	2	P.	P.	Do.		

172	722	4210	66,000	25.50	40.0	1	P.</
-----	-----	------	--------	-------	------	---	----	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	---------

TABLE XI.—Tests of rivets and rivet bars. *Chester Rolling Mills—Continued.*

Lot No.	Tensile tests.								Shearing tests.				Hammer and bending tests passed or failed.	Accepted or rejected.	Manufacturer.	Remarks.		
	Average final				Average original				Nominal size of rivet hole.	Ratio to tensile strength.							Number of tests.	Passed or failed.
	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Average ultimate tensile strength per square inch.	Average original area.	Average ultimate shearing strength per square inch.	Perct.										
	Inch.	Sq.in.	Pounds	Perct.	Perct.	Perct.	Inch.	Sq.in.	Pounds	Perct.	2	P.	P.	Pounds.	Combination Iron and Steel Works.	1/2-inch bar turned down.		
193...	1/2	.680	3,415	66,500	25.00	43.0	2	1	P.	1 1/2	5,200	52,000	78.20	1	P.	Do.		
194...	1/2	.750	4,420	67,000	27.00	43.0	1	1	P.	1 1/2	4,000	57,000	85.08	1	P.	Do.		
195...	1/2	.820	5,420	68,000	27.50	42.0	1	1	P.	1 1/2	4,000	55,000	80.90	1	P.	Do.		
196...	1/2	.890	6,420	69,000	27.00	43.0	1	1	P.	1 1/2	6,600	51,000	80.95	1	P.	Do.		
197...	1/2	.960	7,420	70,000	27.00	40.0	1	1	P.	1 1/2	6,800	52,000	80.95	1	P.	Do.		
198...	1/2	.750	3,360	66,500	27.40	47.5	2	2	P.	1 1/2	6,900	58,000	89.24	2	P.	Do.		
199...	1/2	.820	4,360	67,000	27.75	42.8	2	2	P.	1 1/2	7,000	52,500	75.00	2	P.	Do.		
200...	1/2	.890	5,360	68,000	27.75	42.8	2	2	P.	1 1/2	5,200	56,867	84.21	2	P.	Do.		
201...	1/2	.960	6,360	69,000	27.75	41.0	2	2	P.	1 1/2	3,900	59,000	85.52	2	P.	Do.		
202...	1/2	.750	3,360	66,500	27.50	41.0	2	2	P.	1 1/2	6,933	52,867	78.23	2	P.	Do.		
203...	1/2	.820	4,360	67,000	27.50	43.0	2	2	P.	1 1/2	5,200	56,000	82.61	2	P.	Do.		
204...	1/2	.890	5,360	68,000	27.50	43.6	2	2	P.	1 1/2	3,900	60,000	89.56	2	P.	Do.		
205...	1/2	.960	6,360	69,000	27.50	44.0	2	2	P.	1 1/2	7,000	54,000	81.82	2	P.	Do.		
206...	1/2	.750	3,360	66,500	27.50	39.5	2	2	P.	1 1/2	5,200	56,333	84.92	2	P.	Do.		
207...	1/2	.820	4,360	67,000	27.50	39.5	2	2	P.	1 1/2	6,950	52,000	82.55	2	P.	Do.		
208...	1/2	.890	5,360	68,000	27.50	45.0	2	2	P.	1 1/2	5,200	60,000	91.62	2	P.	Do.		
209...	1/2	.960	6,360	69,000	27.50	38.3	2	2	P.	1 1/2	3,900	58,000	82.86	2	P.	Do.		
210...	1/2	.750	3,360	66,500	27.67	38.3	2	2	P.	1 1/2	7,000	54,000	79.42	2	P.	Do.		
211...	1/2	.820	4,360	67,000	27.67	38.3	2	2	P.	1 1/2	5,200	56,000	83.17	2	P.	Do.		
212...	1/2	.890	5,360	68,000	27.67	38.3	2	2	P.	1 1/2	3,700	59,000	85.50	2	P.	Do.		
213...	1/2	.960	6,360	69,000	27.67	38.3	2	2	P.	1 1/2	5,200	55,500	86.32	2	P.	Do.		
214...	1/2	.750	3,360	66,500	27.90	43.0	2	2	P.	1 1/2	3,750	59,000	91.48	2	P.	Do.		
215...	1/2	.820	4,360	67,000	27.90	43.0	2	2	P.	1 1/2	3,750	59,000	85.90	2	P.	Do.		
216...	1/2	.890	5,360	68,000	27.90	43.6	2	2	P.	1 1/2	6,900	53,000	85.81	2	P.	Do.		
217...	1/2	.960	6,360	69,000	27.90	41.0	2	2	P.	1 1/2	5,180	55,500	86.06	2	P.	Do.		
218...	1/2	.750	3,360	66,500	27.90	40.0	2	2	P.	1 1/2	3,800	54,867	80.40	2	P.	Do.		
219...	1/2	.820	4,360	67,000	27.90	43.7	2	2	P.	1 1/2	6,900	52,000	81.64	2	P.	Do.		
220...	1/2	.890	5,360	68,000	27.90	40.0	2	2	P.	1 1/2	5,200	55,000	83.34	2	P.	Do.		
221...	1/2	.960	6,360	69,000	27.04	38.6	2	2	P.	1 1/2	3,700	53,600	84.51	2	P.	Do.		
222...	1/2	.750	3,360	66,500	27.50	41.0	2	2	P.	1 1/2	6,900	54,000	82.45	2	P.	Do.		
223...	1/2	.820	4,360	67,000	27.50	38.0	2	2	P.	1 1/2	3,710	56,000	86.83	2	P.	Do.		

221	747	4388	63	150	26.90	46.5	3	P	5180	54,500	86.30	3	P	*2,000
...	622	3041	67	200	26.50	39.0	3	P	3700	50,333	80.86	3	P	*2,400
...	624	3058	64	500	24.50	34.5	2	P	3700	56,500	87.60	2	P	*2,400
223	600	1968	60	600	25.30	33.0	1	P	2480	53,000	87.46	1	P	*500
...	624	3050	63	100	27.40	38.5	2	P	3700	62,250	82.60	2	P	*1,800
224	604	2070	63	400	25.30	35.0	1	P	2500	56,000	86.33	1	P	*600
...

*** Accepted.**

General summary.

ACCEPTED RIVETS.

Nominal size of rivet.	Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Number of tests.	Average ultimate shearing strength per square inch.	Number of tests.	Ratio to tensile strength.	Per ct.	Pounds.
1/4	65,200	26.35	43.62	34	52,980	34	81.37	28,119	28,119
3/8	64,900	26.12	42.35	183	53,260	206	82.08	204,000	204,000
1/2	64,552	26.58	41.98	101	54,758	107	84.54	88,925	88,925
5/8	60,929	26.01	36.71	7	53,430	7	87.69	4,200	4,200
All	64,740	27.41	42.00	325	53,695	354	82.94	331,244	331,244

Table XII. gives the results of tests on $\frac{3}{4}$ -inch rivets supplied by Jones & Laughlin, and tested at Pittsburgh by the inspector there. The machine used was that of Park, Bro. & Co. The results agree well with those obtained from similar metal at Chester. The inspection at Pittsburgh was discontinued as a matter of convenience, the tests being subsequently all made at Chester.

STEEL FORGINGS.

Steel shafts have been the subject of special investigation and experiments not yet completed by the Board, and upon which report has been made to the Department. Apart from this class of forgings, the stems, stern-posts, and rudder frames of the vessels are of steel, forged either from scrap or bloom. By forgings from bloom is not meant from a solid piece of metal, but from a number of billets or blooms of convenient size; as they have not so many reheatings as a scrap forging their average quality is better.

Table XIII. contains the record of the physical tests of the larger forgings from scrap and bloom. While the scrap forgings do not give so high average strength or elongation as those from the blooms, they yet give very fair results, and considerably better than is to be expected from wrought iron similarly treated. The average results in the table show the forging from bloom to be about 15 per cent. better metal than that from scrap.

TABLE XIII.

Forging.	Forged from—	Original width.	Original thickness.	Original area.	Ultimate tensile strength, per square inch.	Final elongation in 8 inches.	Final area.
		<i>Inch.</i>	<i>Inch.</i>	<i>Sq. inch.</i>	<i>Pounds.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Stem and stern-post	Scrap .....	.748	.748	.5595	57,100	18.70	42.8
		.750	.740	.5550	55,830	17.30	41.5
		.764	.738	.5638	54,100	18.25	41.3
		.756	.738	.5557	54,000	18.70	42.8
		.750	.750	.5625	60,100	21.00	38.0
Do	Bloom .....	.766	.745	.5707	58,000	24.65	40.0
		.753	.735	.5534	58,700	23.40	34.0
		.765	.742	.5676	57,500	20.30	37.3
Do	Scrap .....	.740	.738	.5461	67,000	18.00	*63.0
		.740	.737	.5453	70,000	24.40	42.0
		.737	.737	.5431	66,800	23.30	44.0
		.741	.741	.5490	65,500	20.70	40.0
Do	Bloom .....	.744	.736	.5475	67,000	22.00	40.0
		.738	.738	.5446	67,000	22.70	39.0
		.745	.741	.5510	68,000	22.80	41.0
		.745	.741	.5483	68,000	20.10	40.0
Rudder frames—Boston and Atlanta.	Scrap .....	.750	.750	.5625	58,666	23.90	55.0
		.567	.550	.3120	58,680	24.30	35.0
Average	Scrap				60,768	19.75	44.74
Do	Bloom				63,037	22.12	38.41

* Piece defective, showing lamination on fracture.

Many smaller forgings from steel blooms or bars have been used in the construction of the machinery for all four vessels. It may be interesting to state these parts in detail, as follows:

STEEL PARTS IN THE MACHINERY OF THE DOLPHIN.

Open hearth steel supplied by the Nashua Steel Company, Nashua, N. H.—Connecting rods, caps, and bolts; piston rods, caps, and bolts; crank-shaft pillow-block caps, and bolts; coupling bolts and cross-keys of line shafting; eccentric rods of main steam and cut-off valves; link bars, pins, connecting bolts, and link blocks of main steam valve gear;

reversing shaft and pins on arms of shaft; keys for securing condenser brackets to the condenser for support of engine cylinders.

STEEL PARTS IN THE MACHINERY OF THE BOSTON AND ATLANTA.

Crucible steel.—Main and cut-off valve stems; bolts for adjusting crank-shaft brasses; all set screws.

Open hearth mild steel, from Nashua, N. H.—Piston rods; main valve rock shafts; high pressure side rods; connecting rod bolts; crank-pins; radial faces of lugs on one disk of clutch-coupling; friction band; gibs and keys, and feathers; coupling bolts; wedges for crank-shaft pillow-blocks.

Cast steel from Chester, Pa.—Pinion on steam turning engine.

Cast steel from Spuyten Duyvil, N. Y.—Cross-heads of air and circulating pump rods.

STEEL PARTS IN THE MACHINERY OF THE CHICAGO.

Mild open hearth steel, from Nashua, N. H.—Bodies of main connecting rods, with their bolts, nuts, and keys; beam center and end pins; crank-shafts and crank-pins; piston rods: main cross-heads; loose couplings of main shafts; cross-heads of main and cut-off valves; gibs and keys of front links; binders of main crank-shafts, with bolts and nuts; bolts and keys of main shaft couplings; rock shafts for main and cut-off valve gear; reversing shaft and binders; main and cut-off rock shaft arms; rock shaft binders and bolts; Stevenson links and blocks; eccentric rods; straps, gibs, and keys for eccentric rods and cut-off rods; bolts securing the beam pillow-blocks to condensers; binders and bolts of beam pillow-blocks.

Crucible steel.—Rods connecting cut-off rock shafts with beam-center pins; valve stems; all set screws.

OPINIONS OF INSPECTORS AS TO DESIRABLE CHANGES IN THE REQUIREMENTS AND SYSTEM OF TESTS.

Before the officers engaged in the inspection of material at the mills and its subsequent working into hulls and boilers should have been detached and ordered to other duty, and in view of the possible action of Congress as to further steel construction for the Navy, the following letter was issued to all inspectors.

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington City, April 24, 1884.

INSPECTOR OF MATERIAL:

SIR: It is the intention of the Board to compile a new circular for "Tests of steel for cruisers," in which the limits of strength and ductility must be adhered to as required by existing law.

You will please give the matter your careful consideration, and report to the Board on or before June 1, 1884, what changes in the present tests as altered by existing orders, and what additional tests, regulations, or restrictions, you consider desirable as suggested by your present duties.

You will please present your suggestions in a concise form ready to be introduced in the circular, and will state your reasons therefor briefly and concisely, and where necessary quote facts and figures from your reports.

Very respectfully,

E. SIMPSON,
Rear-Admiral, U. S. N., President of the Board.

Lieut. F. J. DRAKE, U. S. N.
Chief Engineer B. B. H. WHARTON, U. S. N.
Chief Engineer ISAAC R. McNARY, U. S. N.
Assistant Engineer B. C. BRYAN, U. S. N.
Chief Engineer A. W. MORLEY, U. S. N.
Assistant Naval Constructor J. F. HANSCOM, U. S. N.
Assistant Naval Constructor J. B. HOOVER, U. S. N.
Assistant Naval Constructor R. GATEWOOD, U. S. N.
Lieut. G. A. BICKNELL, U. S. N.

By the replies which follow the Board has been largely guided in its recommendations as embodied in the proposed new circular of "Tests of steel for cruisers." It will be noticed that the changes proposed by the inspectors are, in the main, either in the details of inspection or in the addition of working tests for boiler metal. The few proposed additional requirements for quality as determined by tensile tests are on somewhat debatable ground, and it is believed would result in appreciable increased cost without proportionate improvement of quality.

[Naval Advisory Board, Office of Inspector of Material, Norway Iron and Steel Company.]

SOUTH BOSTON, MASS., May 23, 1884.

SIR: In compliance with your letter of the 24th ultimo, relative to a new circular for "Tests of steel for cruisers," I would respectfully submit the following.

I am, sir, very respectfully, your obedient servant,

F. J. DRAKE,
Lieutenant, Inspector of Material.

Rear-Admiral E. SIMPSON, U. S. N.,
President Naval Advisory Board.

(1) To be inserted after the words "ship plates," in article III., in lieu of "in every lot of 20, &c., * * * shaped according to the annexed sketch."

"Conditions of tests.—All material shall be tested by heats, as follows:

"A specimen bloom of not less than 600 pounds weight, shall be selected at random from each heat, to be cut from the upper third of the ingot. This bloom to be rolled into a plate of 20 pounds to the square foot. Eight test pieces shall be cut from it and shaped according to the annexed sketch—four for tensile stress and four for the heat-quenching test, the four latter, after heating to a cherry red, to be plunged in water at a temperature of 80°F. Thus prepared, it must be possible to bend the pieces under a press or hammer so that they shall be doubled, with faces touching throughout, without presenting any traces of cracking. These test pieces to have the sharpness of the outer edges of one sheared side only taken off with a fine file."

(2) To be inserted in paragraph under "Conditions of acceptance," after the words "original section," so as to read, "with a measured elongation in 8 inches of 18 per cent. at the point of failure, and a final elongation of not less than 23 per cent."

(3) To be inserted in lieu of article under "Cases of failure."

"If the average of these four test pieces, numbered 1, 2, 3, 4 (called test I.), falls below either of the required limits, the *ingot* from which the specimen bloom for pieces 1, 2, 3, 4 was cut shall be rejected, and test II. made, consisting of pieces 5 and 6, cut from the lower third of a second ingot of the same heat. If the mean of the results of these two falls below either of the above limits the entire heat shall be rejected.

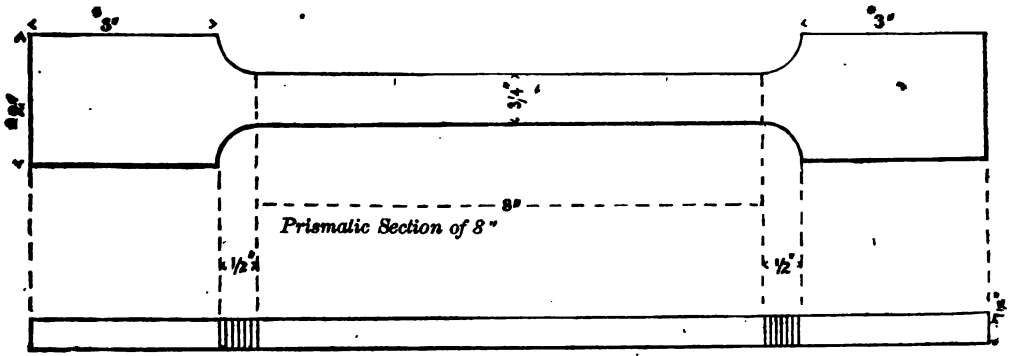
"If it be successful, test III., or the mean of pieces 7 and 8, cut from the lower third of second ingot, shall decide.

"If in any of tests I., II., III., any single piece shows a tensile stress less than 58,000 pounds, or an elongation of less than 18 per cent. at point of failure, or a final elongation of less than 23 per cent., the ingot from which it was cut shall be rejected and the test considered to have failed, regardless of its average."

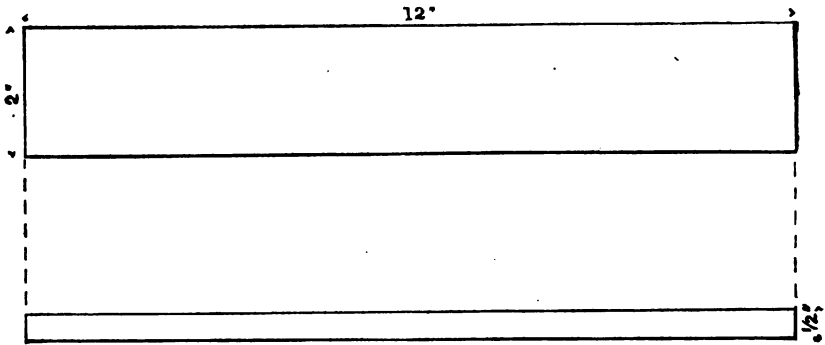
(4) To be inserted in lieu of Article VII.:

"Boiler plates.—Each heat for boiler plate must be subjected to the same tests and in the manner prescribed for ship plates. In each test piece the ductility in 8 inches at the point of failure must not be less than 20 per cent., and its final elongation not less than 25 per cent., and the ultimate tensile strength must not be less than 58,000 pounds and not more than 63,000 pounds, and the average of the tests at least over 60,000 pounds."

The above suggestions are based on facts, as determined by observation from the following heats, which have been accepted. If necessary, more can be quoted to sustain the average already given.

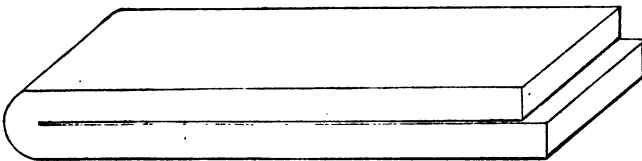
*Sketch of test pieces.*Scale: $\frac{1}{4}$ full size.

For the test machine.



For the quenching test.

[The figures marked thus * may be varied to suit the size of test machine.]



Heat-quenching test. To bend double, faces touching.

Number of heat.	Mean tensile strength of 4 test pieces.	Final elongation in original length of 8 inches.	Elongation at point of failure.	Analysis of—	
				Carbon.	Manganese.
	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>		
39	60,090	27.25	21.00	13	38
43	62,000	25.50	18.25	22	30
45	60,600	26.75	20.75	17	23
64	61,800	26.75	21.00	16	38
65	60,800	28.25	22.00	16	31
66	60,600	27.00	20.25	18	33
67	60,300	26.50	20.00	15	26
99	61,800	26.75	19.75	15	32
112	62,200	26.25	20.00	17	46
114	61,800	25.75	18.00	18	39
118	62,900	27.75	21.75	15	39
120	60,680	26.75	19.50	15	27
182	63,300	25.75	19.00	18	46
192	62,400	26.00	20.50	19	49
195	62,800	26.00	20.00	19	43
205	61,600	27.50	21.00	17	47
274	60,840	26.75	22.75	14	40
275	61,400	27.00	20.25	15	31
325	60,700	26.00	21.00	14	40
327	60,900	27.00	19.50	20	40
346	60,600	26.00	20.00	18	29
353	61,900	26.50	19.50	18	47
380	60,400	26.25	20.50	15	34
390	60,090	26.75	19.50	18	49
406	60,400	25.25	23.00	13	38
410	60,880	27.50	23.50	18	43
442	62,070	26.75	21.50	18	39
450	60,860	26.50	20.25	19	50
452	60,230	29.88	24.00	19	45
470	62,500	26.75	21.50	23	48
Average	61,298	26.81	20.65	17	39

Of the 120 test pieces in the above given heats, only seven fall below 60,000 pounds, as follows:

	Pounds.
Heat No. 39, one test piece	59,966
Heat No. 66, one test piece	59,950
Heat No. 67, one test piece	59,826
Heat No. 325, one test piece	59,796
Heat No. 390, one test piece	59,904
Heat No. 390, one test piece	58,900
Heat No. 452, one test piece	59,625

I do not consider the present crude system of annealing plates of any value whatever, as I find from observations in testing that it does not improve the average elongation or lessen the average tensile stress.

I am, sir, very respectfully, your obedient servant,

F. J. DRAKE,
Lieutenant, Inspector of Material.

Rear-Admiral E. SIMPSON, U. S. N.,
President Naval Advisory Board.

[Naval Advisory Board, Office of Inspector of Material, at Chester Rolling Mills.]

CHESTER ROLLING MILLS, May 27, 1884.

SIR: In accordance with the Board's letter of April 24, 1884, I recommend the following changes:

(I.) In the paragraph headed "In cases of failure," substitute 22 per cent. for 21 per cent.

(II.) In paragraph IV., headed "Quenching test," add "one piece from each plate shall also be bent cold."

(III.) Paragraph VI., "Rivets," should read thus:

"Each 1,000 pounds of rivets from the same heat of metal shall constitute a lot, and be accompanied by two sample bars, each 18 inches long, for tensile test. These samples for tensile test shall be cut from the bars from which the lot of rivets is made, and be stamped with a number, which shall also be placed on each box or package of that lot.

"These samples to be subject to the same tensile test as that required for the plate test.

"The lot of rivets of which the sample bar does not fulfill the requirements of tensile strength and elongation required for plates is to be rejected.

"From each lot six rivets are to be taken at random and submitted to the following tests, two rivets to be used for each test:

"(1) Two rivets to be flattened out cold under the hammer to a thickness of one-half the diameter without showing cracks or flaws.

"(2) Two rivets to be flattened out hot under the hammer to a thickness of one-third the diameter without showing cracks or flaws.

"(3) Two rivets to be bent cold into the form of a hook with parallel sides without showing cracks or flaws."

REASONS.

Since the present inspection by heats or test plates from a sample ingot began, 262 heats have been inspected, and 42 heats have failed to meet the specifications. Of 150 heats ship, about 13 per cent. have failed; average of tests of tenacity 63,000; ductility 25.5. Of 70 heats boiler, the average of tests is—tenacity, 58,000; ductility, 27.5.

The fact that the average of this ship plate shows 25 per cent. ductility, and the proportion of failures is so small, shows that 23 per cent. is an easy standard to meet, and I think justifies the substitution of 22 per cent. for 21 per cent. in paragraph headed "In cases of failures," in the first change recommended.

Again, as originally required, one of the test pieces was to be cut transversely, and the ductility of such pieces is generally much less than those with the grain. To allow or direct the tests to be all longitudinal and leave the 21 per cent. as it was when half of the tests were across the grain is virtually to allow a metal of less ductility to be accepted. The result is that metal can pass which under the original wording could not pass.

I do not know that any advantages are gained by testing across the grain. But testing as is the practice here, I think each heat should be rejected whenever any piece shows less than 22 per cent. ductility.

In assigning a reason for the change II. it seems sufficient to notice that this test has been retained by the British Admiralty after a by no means inconsiderable experience, and I see no good reason why it should not be used for our metal. The failures of the plate to pass the quenching test here have amounted to less than 2 per cent.

Change III. is simply an attempt to indicate that the rivets in lots of 1,000 pounds should be accompanied by samples for tensile test of the bars from which the rivets are made. Selecting one bar from each twenty gives a varying ratio of amount of inspection for each size of rivet, while 1,000 pounds gives a definite one. The other change increases the hammer test from what is *now*, but not above what *was*, originally prescribed.

The fact is sufficiently well known that steel rivets riveted with ordinary care will shear according to their tensile strength in a similar way throughout. I consider the shearing test unnecessary.

Respectfully,

GEORGE A. BICKNELL,
Lieutenant, U. S. N., Inspector of Material.

Rear-Admiral EDWARD SIMPSON, U. S. N.,
President of the Naval Advisory Board, Navy Department, Washington.

[Naval Advisory Board, Office of Inspector of Material.]

PHOENIXVILLE, May 26, 1884.

SIR: In reply to the Board's communication of the 24th April, relating to modifications of the existing test requirements for mild steel, I have the honor to state that, after careful consideration, I see no reason for any modification of the present requirements, which seem to cover the case completely, as regards material to be manufactured by parties unknown to the Board. Any concessions or simplifications should depend entirely on individual circumstances. Thus, if the shapes for additional vessels were to be made of Cambria open-hearth steel, rolled at the Phoenix Iron Works, there are certain changes which might be made with advantage, which would simplify the work and furnish more complete chemical information. These, however, should be made by arrangement, and should not take the form of the successive removal of particular tests from the requirements, but by substitution of an alternate system acceptable to all parties. For a general circular, I consider the present system simple and effective.

Without desiring to enter upon the general subject of the requirements of the law, as bearing on the quality of the material, I beg to suggest that a somewhat harder steel should be used for all shapes, whether for connecting or stiffening purposes, to be accompanied by a clause in the ship specifications requiring the use of improved

punches and shear-knives, a course now being adopted voluntarily in certain bridge works. In all cases, the upper limit of tensile strength should be imposed, both for shapes and plates, from considerations of elasticity; for, as will be seen from the reports of tensile tests, increased tensile strength is accompanied by a rapidly increasing value of the modulus of elasticity,* which may, in particular cases, be further affected by comparatively cold rolling. This consideration is much less important for shapes than for plates, because shapes cannot be rolled below a certain temperature without serious danger to the rolls, and they anneal much more in cooling.

Angles for water-tight work, and beams or frames behind armor or supporting a protective deck, form exceptions to the above considerations and should be made of material not harder than the plates they connect or support.

I have ventured to offer the above suggestions as being in the direction of increased efficiency of the hull and further reduction of scantling, especially in the plating, when backed by the stiffer frames and more rigidly connected at the angles, and after seeing all that this material will stand when tested to destruction.

I have the honor to further suggest that requirements for quality be issued for iron to be used. Thus, certain iron angles made here for the boilers of the Dolphin did not come under inspection. * * *

Very respectfully, your obedient servant,

R. GATEWOOD,

Assistant Naval Constructor, U. S. N.

Rear-Admiral E. SIMPSON, U. S. N.,

President Naval Advisory Board.

[Morgan Iron Works.]

NEW YORK, May 29, 1884.

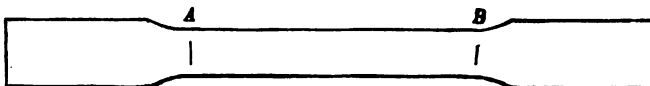
SIR: In obedience to your order of April 24, I have carefully considered the matter of tests of steel for cruisers, and have the honor to submit the following changes, as those taught me as desirable by my recent experience in testing steel. I also include my reasons for advocating such changes, and a list of articles with which I think each inspector should be provided:

I.—TENSILE TESTS.

(1) *Ship plates.*—From each of two plates from each heat of steel, two test pieces shall be cut, one from each end of the plate, one with and one at 90° to direction of rolling.

(2) *Boiler plates.*—From each end of each plate to be used for boilers, one test piece shall be cut, one piece being with and the other at 90° to the direction of rolling.

(3) *Angles, beams, channels, &c.*—From each heat of steel made for angles, beams, &c., a test ingot shall be cast, or a "billet" cut when ingot is bloomed. From this ingot or billet a plate may be rolled and test pieces cut therefrom; or square or round bars may be rolled and used for test pieces. Provided, always, that the steel in test pieces shall receive no more working than the finished material from the heat would have.



(4) *Form of test pieces.*—The test pieces for all plates shall be of the form shown in Fig. 1. The length, A B, must be sufficient to give 8 inches with parallel sides, and have sufficient material cut out to insure the piece from breaking in the grips. The width of piece must be sufficient to give between A and B an area of cross-section not less than $\frac{1}{4}$ or greater than $\frac{7}{8}$ square inch.

When plates are rolled from test ingots or billets for angles, &c., the test pieces shall conform to this pattern, but need only be cut in direction of rolling. If squares are used the side shall not exceed $\frac{1}{2}$ inch. If rounds are used the diameter shall not

* This conclusion must have been deduced from only a few heats, as the average rise in modulus of elasticity with increasing strength for this steel is very small.—N. A. B.

exceed $\frac{1}{4}$ inch; in all cases specimens to be long enough to measure elongation in 8 inches.

(5) *Requirements.*—Each test piece shall be submitted to direct tensile stress until it breaks, and in a machine of approved design. The initial stress to be 35,000 pounds per square inch. The first load to be kept in continuous action for one minute. "Additional loads, &c." (see Section III., Tests of Steel for Cruisers, June 18, 1883,) down to "Conditions of Acceptance." At end of first paragraph under "Conditions of Acceptance" add, "and elastic limit not less than 38,000 pounds per square inch. Cases of Failure: If the average of the four test pieces falls below any of the required limits the heat shall be rejected. In the case of boiler plates, if the average of the two pieces from a plate falls below any limit, the plates shall be rejected. If any single piece shows a tensile strength less than 58,000 pounds or a final elongation less than 21 per cent., the heat from which it came (or, in case of boiler plate, the plate from which it came) shall be rejected, regardless of its average."

II.—QUENCHING TEST.

See Section IV. of "Tests of Steel for Cruisers," June 18, 1884, after the words "without presenting any trace of cracking" insert the following: "Piece to be bent until it breaks or bends double, and fracture of break to be examined. If fracture is crystallized and not fibrous, another piece shall be treated in the same way, and if fracture is similar the inspector may reject the plate, bar, angle, &c., from which it was cut."

III.—STAMPING AND ROLLING TEST PIECES.

A list of all ingots made from each heat for angles or beams, &c., must be furnished the inspector. Each ingot shall be stamped in his presence, with the number of the heat. He shall also see the test billet cut off, stamped, and rolled, and must stamp each plate or bar rolled from it, with a private stamp, in such a way that each test piece will have impression of stamp near one end.

Reasons.

I respectfully state that my reasons for advocating these changes are as follows:

For change in tensile test of ship plates, it reduces the number of pieces.

I have found that the difference caused in tensile strength by rolling at a full red or dull red heat is very marked.

I would call attention to the following heats made at Cambria Iron Works, Johnstown, Pa., for cruiser steel:

Number of heat.	Rolled at bright red heat.		Rolled at dull red.	
	Tensile strength.	Elongation.	Tensile strength.	Elongation.
	<i>Pounds.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Per cent.</i>
4452.....	70,345	25.9	70,573	22.4
4712.....	69,942	24.3	71,954	22.6
4951.....	63,135	24.9	64,060	22.8
4478.....	59,190	28.3	61,590	24.5

A difference is shown here of 2,400 pounds in ultimate strength and 3.8 per cent. elongation, when the difference in heating could scarcely be noticed by any one unaccustomed to heating or working steel. There would, according to this, be a difference in strength and elongation at different parts of a plate if it was not all rolled at a uniform heat. This is found to be true, though when such differences are large they may more properly be attributed to localization of carbon or other elements. In either case, the steel might do for angles and beams or even ship plates; but in boiler plates, where the failure of one sheet is almost sure to cause loss of life and serious damage, every plate should be tested. I have recommended, therefore, a piece to be cut from each end of each boiler plate, and tests for ship plates to come, one for each end of plates from which test pieces are cut. This would detect both the difference made by hot and cold rolling, and also the difference made by unequal diffusion.

I would also require, in specifications for boilers, that every boiler plate flanged,

punched, or heated locally must be annealed after such flanging, &c., has been done. This is required by Bureau Veritas, and Lloyd's rules.

The form of test piece is slightly changed to save labor. From a large number of test pieces, often over two hundred per day, broken in the testing room of Cambria Iron Company, I had occasion to observe that plain flat pieces, without any slotting off from grip ends, very seldom broke in the grips, which was also the case with round and square bars, sheared from rolled length without any further work on them. The original form of test piece, prescribed by the Board, requires a great deal to be slotted or planed off from grip ends; to save labor, I recommend that only sufficient be taken off to insure the piece from breaking in grips. I also found that the use of round or square bars would have saved much labor and expense to the manufacturers of the steel.

The area of cross-section is limited in each case because experience has shown me that measuring elongation for the same length in all cases, the pieces having the greatest area will give greatest elongation. This has also been found the case and written on by M. J. Barba in "*Memoires de la Societ  des Ing nieurs Civils*" (*vide* "*Mechanics*," No. 117, March 29, 1884). M. Barba found as the result of many experiments:

Ratio length of piece to diameter.	Elonga- tion.
	<i>Per cent.</i>
2.51	44.5
3.75	37.5
10.00	28.5

"These results are given as those of round bar-steel, but in the case of bars and plates a corresponding result is obtained."

I have therefore put a limit on the size of the area, since the elongation is to be measured always for 8 inches.

The initial stress is recommended to be 35,000 pounds per square inch, as this is 3,000 pounds below the lowest acceptable elastic limit, and experience has shown me that in calculating the modulus of elasticity for elongations, the results begin to vary very rapidly on approaching the elastic limit of low steel. Thirty-five thousand pounds per square inch seems to give very good results, for which I call attention to my reports of tests of steel at Johnstown, Pa., October, 1883, to April, 1884. The continuation of first strain is recommended to be one instead of five minutes, to save time; and this is an important item where, as at Cambria Works, the machine is in continuous use, and many pieces are to be tested.

It is also recommended to make elastic limit of 38,000 pounds to the square inch a requirement. I think a higher limit with same elongation preferable, but this is suggested to call the attention of the Board that steel can be made with a low elastic limit, not much better, if any, than good iron, and with sufficient strength and elongation to pass specifications.

It is recommended that the inspector be given power to inspect the fracture of a quenching test piece and reject the steel if the fracture is not in his opinion sufficiently good. This is recommended because I have found in quenching pieces a good many from poor heats which bent to requirements of specifications and broke just inside of them and I had not power from specifications to reject the heat. A retest is allowed to be sure that the test piece itself was not burned in heating for quenching. In regard to the system of stamping the test ingots and pieces, I simply wish to call the attention of the Board to the fact that a dishonest firm might make one good heat and use this for all future test pieces. The only way I see to prevent this, without taking the word of the firm, is the system of stamping I propose. This is more important than it would seem at first, for, unless the inspector is certain that his test piece comes from the heat he wishes to test, of course his results are useless. This system will require much careful attention and inspection, but if the word of the firm is to be taken, why inspect at all? Why not take their word that the steel is what is required, and save time and labor?

In conclusion, I would respectfully recommend that the following articles be furnished each inspector, or the inspectors at each place, viz: 1 pair of calipers; 1 four-foot rule (jointed); 1 steel tape for measuring angles, &c. (at least 50 feet); 1 gauge measuring to $\frac{1}{16}$ inch, for measuring test pieces; 1 gauge for measuring final elongation (see sketch A appended); 6 pocket note-books with soft backs, printed according to form B appended; 1 4-quire note-book for smooth work, printed according to form C appended; lead pencils, pens, &c.

If it is required to find elongation under first strain, the inspector should be furnished with an electric contact machine measuring to not more than $\frac{1}{1000}$ (one thousandth) inch, similar to that described in Thurston's "Materials of Engineering," Part II, p. 369. One thermometer for quenching tests, fitted with case to carry in pocket, should also be furnished each inspector who has quenching tests to make.

Very respectfully,

B. C. BRYAN,
Assistant Engineer, U. S. N.

Rear-Admiral E. SIMPSON, U. S. N.,
President of Naval Advisory Board,
Navy Department, Washington, D. C.

FORM B.

Date

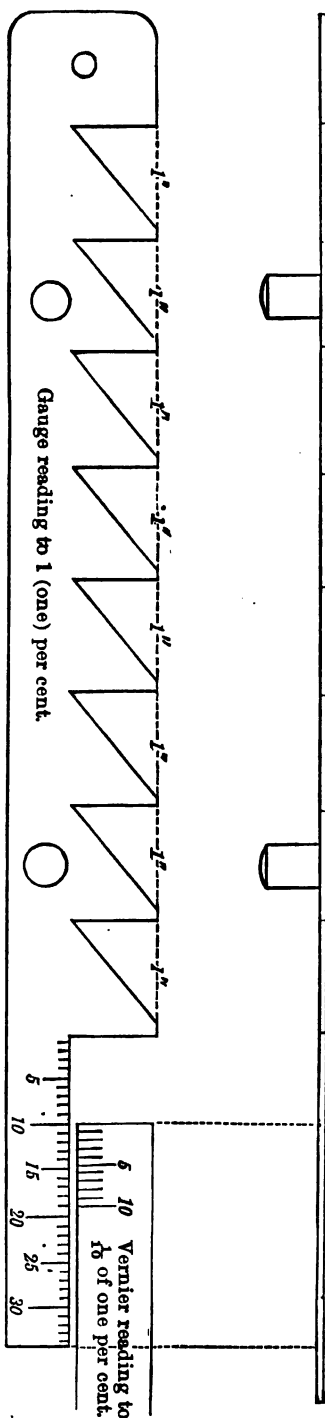
Number of—		C	Mn	P	Si	S		Stress per gauge.	Elongation in 8 inches.
Heat.	Piece.								
Original dimensions..... { — x — — x — — x — — x — }									
Mean dimensions.....									
Area section.....									
Elastic limit (per gauge).....									
Elastic limit (per square inch).....									
Ultimate strength (per gauge).....									
Ultimate strength (per square inch).....									
Fractured.. { Thickness { — } Dimensions { — } Mean — x —									
Reduced area.....									
Reduction of area (per cent).....									
Total elongation (per cent).....									
Time { Commence End.....									
Time of test.....									
Appearance of fracture.....									
Breaking weight per gauge.....									
REMARKS									

FORM C.

Tests of steel for ———, made at ———, by ———.

[illegible]

Gauge for measuring elongation in 8 inches (from design of J. C. Coffin, Johnstown, Pa.).



2000

[Naval Advisory Board—Office of Inspector of Material.]

PITTSBURGH, PA., May 23, 1884.

SIR: In reply to the Board's circular letter of the 24th April, 1884, I have the honor to present the following:

"The initial stress to be as near the elastic limit as possible, which limit is to be carefully determined by the inspector in a special series of tests."

This article in the present circular is not enforced; the initial strain being used is 25,000 pounds per square inch.

Observations to be made of the elongations on a length of 8 inches corresponding to the initial stress, 40,000 pounds and 50,000 pounds per square inch, and after fracture.

The elongations previous to fracture have not been taken, owing to the difficulty and uncertainty without proper instruments. Four elongations would be registered, which would furnish sufficient data, and not be too bulky. These four elongations are about equidistant in regard to stress.

Very respectfully,

L. D. MINER, U. S. N.,
Inspector of Material.

Rear-Admiral E. SIMPSON, U. S. N.,
President of the Naval Advisory Board.

[Office of Inspector of Hulls for U. S. Navy, at the Delaware River Iron Ship Building Works.]

CHESTER, PA., May 21, 1884.

SIR: In compliance with your circular order of the 24th ultimo, I have to state that my duties as inspector of hulls do not warrant any suggestions as to changes in "tests of steel for cruisers," as modified by existing orders from the Board. On the contrary, the results of the work up to the present time go to show that the limitations of the various properties of the material have been wisely determined. Of all the plates, beams, angles, and rivets delivered here for the cruisers, the number of failures have been surprisingly few, and these, in my opinion, only when the pieces were subjected to unreasonable stress while cold. Opportunities for the observance of steel rivets which have been cut out, after having been riveted up, have been numerous, and in all cases have shown evidence of their superior strength and toughness. I am, therefore, as far as my duties enable me to judge, of the opinion that no changes in the existing specifications of tests, in so far as they apply to hulls, should be made.

Very respectfully, your obedient servant,

J. F. HANSCOM,
Assistant Naval Constructor, U. S. N., Senior Inspector of Hulls.

Rear-Admiral E. SIMPSON, U. S. N.,
President Naval Advisory Board, Navy Department, Washington, D. C.

[Office of Inspector of Hulls for U. S. Navy at the Delaware River Iron Ship Building Works.]

CHESTER, PA., May 23, 1884.

SIR: In compliance with instructions contained in Board's letter of the 24th ultimo, I have to state that my present duties as inspector of hulls suggest no reasons for recommending any changes in the "tests of steel for cruisers," as altered by existing orders, and indeed the success which has attended the working of this material for the hulls of the cruisers—the percentage of failures having been remarkably small—does not warrant me in suggesting the adoption of any additional tests, regulations, or restrictions.

Very respectfully, your obedient servant,

JOHN B. HOOVER,
Assistant Naval Constructor, U. S. N., Inspector of Hulls.

Rear-Admiral EDWARD SIMPSON, U. S. N.,
President Naval Advisory Board, Navy Department, Washington, D. C.

[Delaware River Iron Works.]

CHESTER, PA., May 27, 1884.

SIR: I have the honor to acknowledge the receipt of your communication of the 24th ultimo, relating to a new circular for "Tests of Steel for Cruisers," and to report what additional tests or regulations may be considered desirable as suggested by my present duties.

In obedience thereto, I have respectfully to report that, as regards the qualities of, and the manner of making the tests of, materials for the hulls of the cruisers, there are no changes I have to recommend.

In relation to the character of the material employed in their boiler construction, it has been suggested to me that if the limits of tensile strength of the plates were slightly reduced, with an additional increase in the percentage of ductility, a material superior in some particular respects to that now employed would be obtained.

Some of the advantages I claim, and to be greatly desired, are: avoidance of initial stress in the portions of the plates when locally heated, as in flanging; the temper of the material would be less altered round the rivet-holes, as in punching; the process of working more freely and perfectly accomplished; less liability to injury from heavy usage and improper working; can be worked and shaped to form required with greater facility; greater immunity from danger of fracture after boiler is completed.

A number of instances are known where boilers have fractured in testing at a much less pressure than that required to be imposed.

I think it necessary that the manner of making the tests of all boiler-plates be the same as at present prescribed.

I would recommend that the ultimate tensile strength be not less than 56,000 pounds and not more than 60,000 pounds; the ductility in 8 inches to be not less than 28 per cent.

With the increase in the percentage of ductility, the increase of thickness of the plate requisite for strength would be but slight, and necessary only in the cylindrical portion of the shell of the boiler; the strength and rigidity of the flat surfaces being dependent upon the usual methods of bracing. This additional thickness would compensate for corrosion.

All portions of the boilers to be made of the same kind and quality of material.

Very respectfully, your obedient servant,

A. W. MORLEY,

Chief Engineer, U. S. N., Inspector of Machinery.

Rear-Admiral E. SIMPSON, U. S. N.,

President Naval Advisory Board.

[Morgan Iron Works.]

NEW YORK, May 29, 1884.

SIR: In answer to the Board's order of April 24, 1884, to present in a concise form any additions I may think desirable to introduce in a new circular for "Tests of Steel for Cruisers," I have to recommend the following tests for *boiler-plates*:

From one plate rolled from each ingot, a test piece 6 inches wide and 19 inches long must be sheared off cold.

This test piece must then be heated at one end to a bright red heat for not less than one-third of its length nor more than one-half its length, and, while hot, the part marked A in the drawing must be bent round a curve of which the diameter is not more than one and one-half times the thickness of the plate under test.

After the plate is cold and unannealed, holes must be punched of one-eighth of an inch greater diameter than the thickness of the plate, and spaced three diameters from center to center on a line one and one-half times their diameter from edge of the plate, the center of first hole to be three diameters from center of inner curve of bend.

Where the edge of the doubled part meets the surface of the plate, a row of intersecting holes (B) must be punched cold, cutting the plate from its edge to the middle, and then the flange (C), unannealed, is to be bent cold, to a right angle with the plate, with the same curve as A. All plates accepted must show neither cracks nor flaws after these tests.

If a piece fails, *all* the plates rolled from the *same* ingot must be tested.

REASONS.

The necessity of an addition to the admirable tests ordered by the Board is proved by the numerous failures of material having the inspector's mark. In my opinion the tests should be as severe as the punishment which the metal receives during the ordinary operations in making a boiler.

The test I propose is practicable and not expensive; it will show in *one* piece the effects of shearing, punching, bending hot and cold, and also local heating. Good mild steel suitable for boilers should stand this test in *addition* to those now in force.

Very respectfully,

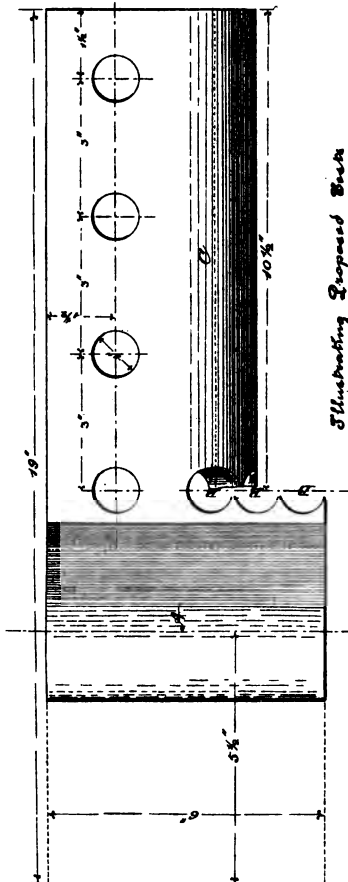
ISAAC R. McNARY,

Chief Engineer, U. S. N.

Rear-Admiral E. SIMPSON, U. S. N.,

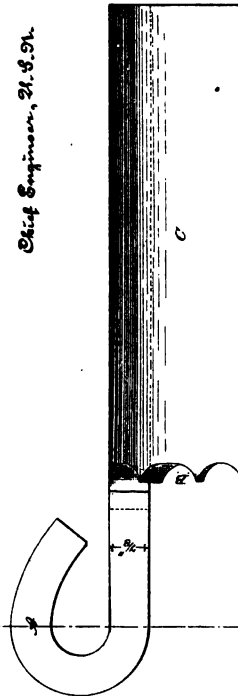
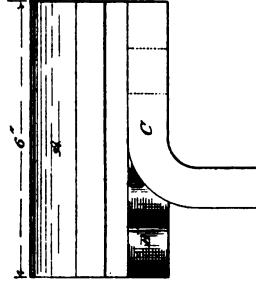
President Naval Advisory Board.

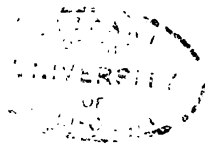
Plate IV.



Illustrating Proposed Boiler
Steel Boiler Plate.

James R. McHenry,
Chief Engineer, U.S.N.





[Morgan Iron Works.]

NEW YORK, May 27, 1884.

SIR: In reply to your letter of April 24, I would state that I have carefully considered the matter of "Tests of Steel for Cruisers" more especially with reference to material used for boilers, and I have little to add to a subject which has been so much discussed of late years.

So far as my experience goes with boiler-plates of mild steel, I do not think it has yet been made with that certainty as to its homogeneity that is desirable for full confidence in it. I think this is more a question of the thorough mixing of the ingredients in the furnace previous to the casting of the ingots than their quantity or quality. Of course the better the ingredients the better, as a whole, the resulting material.

I think that greater stress should be laid on the elastic limit when tests are made, as practically that is the measure of strength. Reduction in the tensile strength and elongation required by existing specifications should not be thought of, but rather an increase of the former demand, for I can see no advantage to be gained by the use of this material over that of wrought iron if the tensile strength of the former remains equal to or little superior to that of the latter.

In the working of these plates for boilers, it appears to be a fact that when they have stood well the tests, both cold and hot, they fail when worked at a heat not luminous, or what is known as a "black heat." This must take place to a greater or less degree during the process of flanging and local heating in fitting up. A remedy for this, to a degree at least, would be the flanging of the plates at the time and place of manufacture, where facilities are better for total and even heating and cooling. This would also obviate much of the delay and expense of rejecting the plates at the time and place of manufacture of boilers, or much of the flanging could be done with the plate cold. If a plate is capable of being bent cold to the degree required by the specified tests of the Board without injury, why should it require heating for flanging where the bend is less? I am of the opinion that all rivet, stay, and brace holes should be drilled, and where plates are lapped or butt-strapped one plate should be used in place as a template for drilling the others. I would advocate this apart from any consideration as to the effect upon the plates of punching, and with a view to the accuracy of the holes in the plates and straps with regard to each other, and, as a consequence, the banishment of the drift-pin from the boiler-shop. In the case of steel shafts it is a question whether they should possess great elongation, especially when obtained at the expense of hardness and rigidity. I would prefer they should have a high elastic limit with a moderate elongation.

Very respectfully,

B. B. H. WHARTON,
Chief Engineer, U. S. N.

PROPOSED NEW CIRCULAR OF TESTS.

From the foregoing reports of inspectors, and some of the general results obtained from time to time during this inspection, a new circular has been compiled, embodying certain alterations in the system of tests without any change of requirements. The principal alterations will be found in the shape and proportions of the test piece, in the method of removing and stamping the test specimens, and in following out the material of each heat, and in the return to the individual test for boiler-plate.

TESTS OF STEEL FOR CRUISERS.

Instructions to Inspectors.

NAVY DEPARTMENT,
Washington, ——— 188—.

The following rules are prescribed in order to insure the fulfillment of the clause of the act of Congress of August 5, 1882, "Such vessels * * * to be constructed of steel of domestic manufacture, having as near as may be a tensile strength of not less than 60,000 pounds to the square inch, and a ductility in 8 inches of not less than 25 per centum."

I. All ship plates, beams, angles, rivets, bolts, boiler-plates, and stays to be inspected and tested at the place of manufacture by a naval inspector of material, and to be passed by him, subject to restrictions hereinafter mentioned, before acceptance by the ship-builders, whether Government or private, for incorporation into said vessels.

II. Every plate, beam, and angle supplied for these vessels to be clearly and indelibly stamped in two places and with two separate brands: (1) with that of the maker, which shall distinguish the name of the manufactory or company, (2) with the regulation brand of the naval inspector of material. The latter not to be stamped upon any of the above-mentioned material until it shall have passed an inspection for surface or other defects of manufacture and the physical tests, have been accepted by the inspector, and have been stamped with the maker's brand.

In case of small articles passed in bulk, the above-mentioned brands shall be applied to the boxing or packing material of the objects.

No steel material to be received at the building yards for incorporation into vessels except it bear, either upon its surface or that of its packing, both of these brands, as evidence that it has passed the necessary Government inspection.

III. The weight of all plates, beams, angles, &c., must be obtained by the inspector of material before delivery.

Plates of $12\frac{1}{2}$ pounds per square foot and less, and strips and bars of 6 pounds per lineal foot and less, may be accepted if the weights vary between 3 per cent. above and 5 per cent. below the specified weights.

All other plates and shapes may be accepted if the weights vary between the specified weights and 5 per cent. below them.

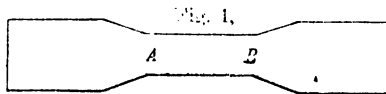
All plates and shapes not being within the limits here specified may be rejected.

TESTS.

All material except boiler plates should be tested by heats, as follows:

A specimen ingot or bloom shall be selected and rolled into a plate or bar and test pieces cut therefrom, provided always that the test pieces shall have received no more working than that which the finished material from the heat would receive.

Four test pieces of the form shown in Fig. 1 for plates—a square or round, in condition as finished at the rolls, may be used for tests of shapes—shall be made and tested for each heat.



The length A B must be at least 8 inches of uniform cross-section of which the area should not be less than $\frac{1}{2}$ or more than $\frac{8}{10}$ of 1 square inch.

The reduction of breadth throughout the length A B should be just sufficient to prevent failure in the grip.

The test pieces must not be annealed unless the finished material is to be annealed.

Each test piece shall be submitted to a direct tensile stress until it breaks, and in a machine of approved character.

The initial stress to be 30,000 pounds per square inch.

The first load to be kept in continuous action for one minute. An observation to be made of the corresponding elongation measured upon the original length of 8 inches.

The stress to be then increased slowly until the principal elastic limit is determined, after which additional loads will be added at intervals of time as nearly as possible equal, and separated by half a minute; the loads to produce an increase of stress of 5,000 pounds per square inch of original section of the test piece until the stress is about 50,000 pounds per square inch of original section, when the increments of stress should not exceed 1,000 pounds per square inch. Upon close approach to the probable ultimate strength, the load to be increased gradually and its maximum value carefully noted.

The final elongation to be that obtained after rupture.

A list of all ingots made from each heat must be supplied to the inspector. Each ingot should be stamped in his presence with the number of the heat. He should also see the test plate or billet cut off, stamped, and rolled, and place a private stamp upon it in such a way that each test piece will have the impression of the stamp near one end.

CONDITIONS OF ACCEPTANCE.

In order to be accepted, the average of the four test pieces must show an ultimate tensile strength of at least 60,000 pounds per square inch of original section, and a final elongation in 8 inches of not less than 23 per cent.

Material which shows a strength greater than 60,000 pounds per square inch will be accepted, provided the ductility remains at least 23 per cent.

CASES OF FAILURE.

If the average of these four test pieces, numbered 1, 2, 3, 4, (called Test I.), fall below either of the required limits, the ingot from which pieces 1, 2, 3, 4 were cut shall be rejected, and Test II. made, consisting of pieces 5 and 6, cut from a second ingot. If the mean of the results of these two fall below either of the above limits, the entire lot shall be rejected. If it be successful, Test III., or the mean of pieces 7 and 8 cut from a third ingot shall decide.

If in any of the Tests I., II., III., any single piece shows a tensile stress less than 58,000 pounds or a final elongation less than 21 per cent., the ingot from which it was taken shall be rejected and that test considered to have failed, regardless of its average.

QUENCHING TEST.

IV. A test piece shall be cut from each plate, angle, or beam, and after heating to a cherry red, plunged in water at a temperature of 82° F. Thus prepared it must be possible to bend the pieces under a press or hammer so that they shall be doubled round a curve of which the diameter is not more than one and a half times the thickness of the piece tested without presenting any trace of cracking.

These test pieces must not have their sheared sides rounded off, the only treatment permitted being taking off the sharpness of the edges with a fine file.

Inspectors may require a cold bending test when considered necessary.

ANGLES, BEAMS, BULB BARS, T BARS, &.

V. Angle bars are to be subjected to the following additional tests: A piece cut from one bar in twenty to be opened out flat while cold under the hammer; a piece cut from another bar in the same lot shall be closed until the two sides touch while cold.

Bulb and T bars are to be submitted to a closing test similar to that prescribed for angle bars.

Bars submitted to these tests must show neither cracks, cliffs, nor flaws.

RIVETS.

Each 1,000 pounds of rivets from the same heat of metal shall constitute a lot and be accompanied by two sample bars, each 18 inches long for a tensile test. These samples for tensile test shall be cut from the bars from which the lot of rivets is made and be stamped with a number which shall also be placed on each box or package of that lot.

These samples to be subject to the same tensile test as that required for plates.

The lot of rivets of which this sample bar does not fulfill the requirements of tensile strength and elongation required for plates is to be rejected.

From each lot six rivets are to be taken at random and submitted to the following tests, two rivets to be used for each test:

(1) Two rivets to be flattened out cold under the hammer to a thickness of one-half the diameter without showing cracks or flaws.

(2) Two rivets to be flattened out hot under the hammer to a thickness one-third the diameter without showing cracks or flaws.

(3) Two rivets to be bent cold into the form of a hook with parallel sides without showing cracks or flaws.

BOILER PLATES.

Two tensile test pieces shall be cut from each plate rolled for boilers and one quenching test piece, which shall be tested as before described; except that, in the tensile tests, the initial stress may be 25,000 pounds to the square inch.

The ductility in 8 inches must not be less than 25 per cent., and the ultimate tensile strength must not be less than 57,000 pounds, and not more than 63,000 pounds; and no single piece must show a less tensile strength than 57,000 pounds to the square inch.

No steel for boilers which is to be worked at a heat or to be annealed after working in the boiler shop shall be annealed at the works.

The acceptance of material under these tests will not relieve the contractor from the necessity of making good any material which fails in working or may be rejected by the inspector.

PROPOSED DETAILED INSTRUCTIONS TO INSPECTORS OF MATERIAL.—In accordance with the experience gained, the method of conducting the tests and inspection may with advantage be modified as contained in the following instructions. The principal changes are in the method of conducting the tensile tests, the addition of a cold bending test under certain conditions, and more explicit directions as to the quenching test.

DETAILED INSTRUCTIONS TO INSPECTORS OF MATERIAL.

NAVAL ADVISORY BOARD, NAVY DEPARTMENT,
Washington, ———, ———, 188—.

In addition to the instructions contained in the requirements for "Tests of Steel for Cruisers," inspectors will be guided by the following :

(1) TESTING APPARATUS AND METHODS OF TESTS.

The inspector will, as soon as practicable, after reaching his post, carefully examine all the appliances available for the proper inspection of material, consult with the superintendent as to making the tests, and make a special detailed report to the Advisory Board of the kind and efficiency of the apparatus and the arrangements which have been decided upon for making the different tests. Such report to include a description of the testing machine to be used, accompanied by a cut, or if possible, detailed drawings from the maker; whether the machine is worked by hand or power; if hydraulic, the condition of the pumps, valves, leading pipes, plunger packing, &c.; the method of holding the pieces in straining, a record of any dead weight tests for accuracy which may have been made at the works, and the feasibility of repeating them; the measuring instruments in use or available; the proposed method of heating the pieces for quenching test, and, if in a furnace, a description of it, including whether or not the pieces will be in direct contact with the flame, the kind of fuel used, and the degree of control exercised over the flame; the proposed method of bending such pieces, and, in the case of inspectors of material for shapes or rivets, the methods of making the special tests required for such material; and finally whether or not all such facilities and proposed methods are sufficient for, and in accordance with, the determinations of such quantities and the observance of such precautions as are contained in the requirements of "Tests of Steel for Cruisers" or hereafter in these instructions, together with such other matters as he may consider of importance.

(2) METHODS OF MANUFACTURE.

He will render himself as familiar as possible with the principles and details of manufacture of the material at the works at which he is stationed, paying special attention to the manipulation and heating of the material. But he will take care to conduct his inquiries only so far as he may be willingly accorded facilities by responsible persons. In no case shall he attempt to exercise any control whatever over the manufacture beyond the actual testing, inspection, weighing, and stamping of the material, except as regards annealing of steel intended for certain parts of boilers, as duly specified in the "Tests of Steel for Cruisers," and as hereafter mentioned.

(3) RECORD OF INSPECTION.

He will keep a complete record of every piece of metal tested for the Government, in accordance with the blank forms and note books furnished, with such other items as he may deem necessary, whether such piece fulfills the requirements of a successful test or not.

(4) REPORTS.

At the end of each week he will make a detailed report of tests and inspection to the Advisory Board, together with such information or suggestions as he may deem necessary in carrying out the work.

(5) ALLOTMENT OF MATERIAL—REGISTER MARKS.

For purposes of recognition and record, all plates, beams, and bars are to be divided into lots of twenty pieces as finished by the rolls, and each piece and its corresponding test piece or pieces marked with a distinguishing register mark, consisting of a number and one of the first twenty letters of the alphabet, the number to denote the lot, and the letter the individual piece in the lot. Lots of material shall be numbered consecutively in the order in which they are inspected, ship and boiler material separately; and, as far as possible, all the pieces of a lot shall be from the same cast or heat, the heat number being rigidly followed from the cast to the finished product.

The register mark of rivet bars and rivets will consist of the lot number alone.

The register mark shall be legibly painted on each piece of material, plates near one corner, angles on the inside, beams on the web; the paint to be mixed with

benzine or such other substance as will effectually resist the action of the weather for a long time; the corresponding test pieces to have the register mark stamped cold near one end. In the case of test pieces taken across the direction of rolling, a cross (+) will be affixed to the register mark on the test specimen.

(6) REMOVAL OF TEST PIECES.

While the inspector is to use his judgment as to the part of the material from which the test pieces are taken, he will in no case, except by the request or permission of the superintendent or other responsible officer of the works, intrench upon the finished measurements of the piece in removing them. As far as possible, pieces of the scrap will be taken, and, if they fulfill the requirements, the piece will be passed. Should they fail, however, the piece need not thereby be condemned; but the inspector, if he so desires, or at the request of the superintendent, may make a second test of a piece taken from the body of the material. Test pieces, especially of shapes, may be removed by the hot saw, with due precaution as to the correspondence of the piece and test specimen. Pieces for cold bending, opening, or closing tests are preferably so removed, and, if removed by shearing, no part of the test piece should have been under the shear-knife.

In removing the tensile test pieces from the specimen plate of a heat of material for ship plate, the original top and bottom of the ingot shall be noted and the pieces numbered systematically accordingly. Similarly for boiler plate, the pieces being removed as far as possible from diagonally opposite corners.

(7) CONDEMNATION OF MATERIAL AND CASES OF DISAGREEMENT.

All condemnations of material will be immediately reported to the superintendent of the works, or his authorized representative, who shall have access to the entire record of tests and weights. Test pieces connected with such cases shall be preserved until their removal is authorized by the Board.

In case of any disagreement arising during the inspection, the matter shall be at once referred to the Advisory Board for settlement. It is, of course, preferable that all tests shall be made in the presence of a qualified representative of the management of the works.

(8) THE TENSILE TEST.

(a) *Tensile test pieces.*—In removing such pieces from plates, care should be taken that they are curved as little as possible, and in subsequent cold straightening they should not be treated in such a way as to materially hammer-harden them. If removed by punching, a margin of not less than one-eighth of an inch will be left all around the finished dimensions, to be removed by a cutting tool in shaping. All other tensile test pieces requiring to be shaped should be removed by a cutting tool, and should have been perfectly straightened while hot as finished by the rolls. When the modulus of elasticity is to be determined, the degree of straightness of the piece should be carefully noted.

As the original sectional area of the pieces is to lie between certain limits, it is suggested, for convenience in the preparation of the pieces, that a series of wooden templates be prepared of dimensions suitable to graded thicknesses and marked accordingly with distinguishing marks to be placed on the specimens after straightening, for the guidance of the mechanic in roughing them out.

(b) *Measuring the piece.*—The original sectional dimensions of the prismatic portion of the piece shall be obtained in at least three places, viz, in the middle and near each witness mark. If the sectional area at the middle be the least of the three, the corresponding dimensions shall be taken for test. If either of the other sections be less than at the middle, a mean shall be taken between the dimensions of the least section and at the middle. In any case should the difference between the sectional areas in any two places be greater than 3 per cent. of the greatest area, the test piece shall be discarded as unfit for test.

(c) *Extension under initial stress and modulus of elasticity.*—In placing the piece in the grips, care should be taken that it is perfectly central, and the grips must not be so made, or allowed to get into such a condition, as to hold a flat piece chiefly on one side. When the initial extension is to be measured, a stress of about 10,000 pounds to the square inch shall be put on and removed to tighten the piece in the grips and remove low initial strains.

Suitable and approved apparatus being obtained or provided, the extension in the measured length of 8 inches under the initial stress of 30,000 pounds or 25,000 pounds to the square inch, as prescribed in the "Tests of Steel for Cruisers," shall be measured, if possible, within the one minute allowed for such initial straining. Then the

modulus of elasticity will be 240,000 or 200,000 pounds, for ship and boiler material respectively, divided by the corresponding observed extension and be recorded to the nearest 1,000 pounds. Great care should be exercised in making this observation that the proper stress is uniformly maintained and the measuring apparatus is in no way disturbed.

(d) *Principal elastic limit.*—The elastic limit is to be obtained as follows: The load being slowly increased above the initial load, the beam closely following the pump or screw so as practically to maintain a balance at all times, there comes a time when the beam momentarily no longer rises to the pump or screw. At the same time, scrutiny of the surface of the test piece shows that the adhering mill scale is just commencing to flake off, generally near the fillets. Both indications should be observed when practicable. The corresponding stress will be recorded as the elastic limit, and should be obtained to the nearest 10 pounds.

(e) *Ultimate tensile strength, or tensile limit, and the corresponding extension.*—Further increase of stress having been applied by such increments and at such intervals of time as prescribed in the "Tests of Steel for Cruisers," when, in the judgment of the inspector, further stated increment of stress would pass or closely approach the maximum resistance of the piece, the increase of stress shall be applied continuously, following the pump or screw, until the maximum indication is obtained and the beam drops. At the same time, the extension of the piece should be measured as carefully and accurately as possible. The ultimate strength should be recorded to the nearest 10 pounds.

(f) *Final strength or resistance.*—Following tensile limit, the extension of the piece should proceed slowly and uniformly, and a practical balance should be maintained by the beam so that at the moment of rupture the corresponding resistance may be accurately obtained. This load divided by the fractured area subsequently obtained gives the actual resistance of the metal to separation, and should be recorded to the nearest 100 pounds.

(g) *Final elongation.*—In removing the pieces from the grips, care should be taken that the fractured surfaces are not abraded or struck against any hard substance, so that the two parts may be neatly fitted together. The fitting is best done in a suitable frame and so that the fractured area can be immediately measured without change of position. When fitted, the parts may be lightly tapped together. The increase of length may be measured either directly in per cent. by suitable scale with vernier attachment, reading to the nearest tenth of 1 per cent., or in inches to the nearest thousandth, with subsequent division by 8 to reduce to per cent. All elongations after rupture, or at tensile limit, should be recorded to the nearest tenth of 1 per cent.

(h) *Final area in per cent. of original area.*—The pieces having been fitted together, as above described, the width of the least section will be measured and its thickness at each edge and at the middle in the plane of least width. Then the sum of the thicknesses at the edges, plus 4 times that at the middle, divided by 6 will be the mean thickness, to be multiplied by the least width, as measured, to obtain the fractured area; the fractured area to be divided by the original area, and the quotient, expressed in per cent. to the nearest tenth, entered in the proper column.

(i) *Fracture.*—The fractured surfaces will be examined with a pocket lens and any evidences of lamination will be recorded. The nature of the fracture also, whether bright or silky, dull, fine or coarse crystalline, and the arrangement of the surface of fracture, whether plane, double plaque, cup, or irregular, will also be noted.

(9) THE QUENCHING TEST.

In making this test, it is necessary to observe certain precautions. If the pieces are heated in a furnace, the flame should be kept neutral, i. e., neither smoky nor cutting, and, if possible, they should be heated by radiation only, out of contact with the flame. If heated in a smith's forge, the fire should be covered or built up, and the blast regulated so that the flame is neither smoky nor cutting. In such a fire only coke should be used, and a green or fresh fire will not give the best results. Especial care should be taken that the pieces are uniformly heated. A low cherry red is the desirable temperature, and the pieces should in no case be allowed to cool down from a higher temperature before being placed in the water.

No piece used for quenching or cold bending test may be less than 10 inches in length and 2 inches in width, except in case of angles too small to allow this width, when the greatest width possible is to be taken.

In bending all pieces, the inspector will not permit any nursing on the one hand or unfairly violent treatment on the other. If the bending is done under the hammer, the blows should be delivered as square to the surface as possible. In all cases uniformity of treatment should be observed.

(10) COLD BENDING TESTS:

Should any plate, beam, or bar be finished at the rolls at a very dull red or colorless temperature—or for other sufficient reason—a piece shall be removed as prescribed

for the quenching test, and must bend cold to the same extent without crack or fracture, except that such pieces may be removed by a cutting-tool, or, if removed by shearing, the sheared edges may be ground off to any desired extent. In case of failure, the piece shall be rejected.

(11) SPECIAL COLD TESTS OF ANGLES, BEAMS, AND TEES.

The length of pieces for these tests may be not less than 8 inches, to be removed and prepared as previously stated. If bent under a hammer, the blows should be delivered square to the surface.

While the apparent severity of these tests is recognized, no material which has successfully passed the other tests will fail under them unless it be badly laminated or threaded with dirt. In case of failure, the piece shall be rejected and another piece of the same lot tested. Should the failures be numerous, the fact will be immediately reported, and the inspector shall call the attention of the manufacturer to it so that steps may be at once taken to obtain sounder ingots or blooms.

(12) TEST PIECES TO BE RETAINED.

All tensile test pieces, and such other test pieces as may have given rise to dispute or disagreement between the inspector and the authorities of the works, shall be retained until such time as the Advisory Board may permit their removal. Other pieces, which may present any features of special interest in the judgment of the inspector, or have been the subject of special mention or report by him, shall likewise be retained.

(13) ANNEALED PLATES.

Ship's plates may be annealed at the discretion of the manufacturer, but the inspector will understand that no boiler material may be annealed unless expressly authorized by the Board or by the inspector of machinery under its instructions.

(14) GENERAL INSPECTION.

The inspector, or his duly qualified assistant, shall see each plate as finished by the rolls, and each bloom or bar on commencing a rolling, or in case of any difficulty in the rolling, and shall exercise a general supervision at all times as to the condition of the piece as finished by the rolls, especially observing any fluting of plates due to irregular wear of the rolls, any evidences of overheating or too cold finishing, any severe mechanical treatment in straightening at a black heat or when cold. Cold plates should be carefully examined on each side for signs of lamination, or fine cracking, sand or scale marks, scabs, and surface defects generally. Plates must not be cut too near any locally defective portion. Shapes will be likewise examined for surface defects, and, in addition, the width of flanges will be measured, with special attention to symmetry of sections for beams and tees; shaded backs of angles and grooved fillets from careless dressing of the rolls are to be avoided. In all such cases, and others which may arise during this inspection, affecting the excellence of the finished material for the purpose intended, the inspector must exercise his judgment as to the magnitude of the defect, and consult with the responsible parties in regard to rectifying the trouble or rejecting the piece, except in such cases as may be provided for by appropriate test.

(15) WEIGHING MATERIAL.

Each plate, or all the parts into which a plate as finished by the rolls may have been cut, will be weighed, and must fall within the specified limits. In weighing shapes, all beams and bars of the same size and weight per foot of the same rolling should be weighed separately, in quantities, as far as possible, of not less than 2,000 pounds net at one time. The limits of weight may not be satisfied by mixed loads of light and heavy bars; and no single bar which there is reason to believe is without the prescribed limits may be shipped without the special permission of the Advisory Board. In commencing a rolling of shapes, or after the setting of the rolls has been interfered with, the inspector shall inform himself of the results of the sample pieces weighed for the guidance of the roller, and such bars as there is reason to believe do not satisfy the requirements in this regard may be rejected for that order. But every piece rolled, unless defective in shape or finish, should be tested for quality. It should be noted, however, that all parts of a beam or bar will not weigh alike, and the front end will generally be the lightest.

(16) STAMPING THE MATERIAL.

The inspector will be provided with two stamps, the Naval Inspection brand and one of his own initials, both of which shall be affixed to each piece of material when ready for shipment, but only after having passed satisfactory tests and inspection and being within the prescribed limits of weight. Such stamps shall be affixed as near as possible to the register mark for the better identification of the piece.

NOTE.—As soon as possible after reaching the works, the inspector shall request the Superintendent to have made, or otherwise obtain, a special sledge of about the ordinary size and weight, of soft iron or very soft steel, as the stamps are expensive and necessarily of too high temper to absorb the work of many blows from a hard-faced sledge without breaking up.

(17) INCIDENTAL EXPENSES, INSTRUMENTS, STATIONERY, &C.

All instruments, books, and stationery required for use in the inspection will be procured by requisition on the Advisory Board, and receipts will be rendered to the Board for all material received.

Incidental postage and telegraph expenses will only be reimbursed through bills made to, and approved by, the Advisory Board.

Expenses for travel will only be reimbursed by the ordinary naval rule of mileage on orders from the Department.

Unless absolutely impracticable, no official expense will be incurred by the inspector without a preliminary authorization from the Advisory Board.

Approved:

_____, *U. S. N., President of the Naval Advisory Board.*

_____,
_____,
Secretary of the Navy.

RECORD OF TESTS.

For the better record of tensile tests, inspectors should be supplied with note-books ruled in accordance with the sample page (Plate V.)—filled in for better illustration—which shall form part of the inspector's records and be signed by him at the end of each series of tests reported in tabular form to be described. The items in the note-book are believed to contain all necessary information of the circumstances and details of tests, and can be at any time referred to in the event of any discrepancy arising, or for more particular information on any point not contained in the tabular form. The page should be printed on one side only, the other being used for remarks and the details of calculation. Thin paper of good quality should be used, so that many tests may be recorded in a single book, which may yet be conveniently carried on the person. Printed copies of the requirements of "Tests of Steel for Cruisers" and of the "Detailed Instructions to Inspectors of Material" should be bound in the note-book, together with several blank pages for the entry of any subsequent instructions.

The condensed tabular form for report and record (Plate VI.) contains the chief features and results of tests, and is believed to embody as much information as can be obtained under the circumstances of an ordinary test. The results so recorded are in a form suitable for analysis.

PLATE V.

Date, 9 | 19 | 84.

Heat.—5565 Piece.—4 Condition.—Straight.

Carbon .22% Manganese .54% Phosphorus %	Stress per sq. in.	Gauge load.
Initial extension .00805 $E=29,815,000$	30,000	16,044
..... Original width. Original thickness	35,000	18,710
Marked end 1.244 × .433	45,000	24,070
Middle 1.240 × .432	50,000	26,740
Unmarked end 1.234 × .432	51	27,270
Taken as 1.238 × .432	52	27,800
Sectional area ..... .5348	53	28,330
Elastic limit (gauge) 22,800	54	28,860
" " (per sq. in.) 42,635	55	29,390
Ult. ten. str. (gauge) 35,860	56	29,920
" " (per sq. in.) 67,050	57	30,450
Ext. at tensile limit 1.54 ins. 19.25%	58	30,980
Final elongation — ins. 23.3 %	59	31,510
Time { Commence 2 hrs. 8½ mins	60	32,040
{ End 2 hrs. 21 mins	61	32,570
{ Of test 12½ mins	62	32,100
Final gauge load 31,000	63	32,630
" stress per sq. in. 104,870	64	33,160
Fractured area.—	65	33,690
t_1 = .319	66	34,220
t_2 .303 4 t_2 = 1.212		
t_3 = .311		
6) 1.842		
Mean thickness .... .307		
Fract. width ..... .963		
" area ..... .2956 Ditto % 55.28		
Fracture.—Silky, irregular cup.		

PART III.

COMMERCIAL TESTING.

The primary object of all commercial testing is to insure sufficiency of strength in the finished structure, and, in general, also, the manufacturer desires to protect himself from the delays and additional expense due to failures of material in working. The nature of these tests, therefore, is always such as to subject the material to extreme cases of the stresses developed in the structure and during construction. The application of mathematical theories and special systems of scientifically-conducted tests allow the structural stresses to be resolved into the three principal stresses of tension, compression, and shearing, and certain permissible limits of corresponding resistance to be applied in each case. Whenever possible, loads producing sufficiently extreme stresses are applied to the finished structure, notably in the case of boilers and bridges, when the manufacturer becomes specially interested in the qualities of resistance of the materials employed, and, if responsible, resorts to preliminary testing in order to insure them. When the structure cannot conveniently or at small expense be subjected to sufficiently extreme stress to insure at once the excellence of material and workmanship, it becomes necessary for the manufacturer to work to specifications supplied by the consumer, who must then ascertain that the material possesses the requisite qualities by such tests as he may deem necessary. Even when the structure can be subjected to proof, the large direct and incidental cost of failure under proof, or subsequently, very generally makes it desirable for the consumer to supply specifications, by which course, also, he largely controls the cost of production.

Accordingly many systems of small testing have been used, in which, by tests carried out on representative small pieces, it is sought to insure efficiency of strength and other qualities in the structure. As to just how far the results of these tests are representative of the material in the structure and should form the basis of designs, engineers differ, and special tests on a large scale are required to give them definiteness. The differences thus developed are due to three main causes—(1) lack of knowledge of the laws governing stress and strain in pieces of different sizes and proportions, (2) want of uniformity in the quality of the material, and (3) initial stresses set up in manufacture. Of these the first presents a large field for special inquiry by no means exhausted; the second may be covered, to a certain extent, by properly-devised tests on a commercial basis, but is well supplemented by special research as to the main causes; to avoid the third constitutes good workmanship, the chief source of reputation to the manufacturer. The last cause of difference is evidently widely variable, though mechanical appliances are narrowing its limits. It constitutes one of the chief necessities for the requirement of high ductility so common in connection with the material for built-up structures. Could these initial stresses be avoided, a much harder and stronger material could be used in the large majority of structures, with a diminished factor of safety and great consequent lightness. But the average conditions of working often necessitate a quality of material such that it may undergo

considerable strain or distortion without approaching dangerously near its ultimate strength. In some cases, also, as in the bottom plating of vessels subject to grounding, in those portions of a boiler in contact with the fire, or in the plating and framing behind armor in armor-clad vessels, the quality of high ductility in the material is especially necessary for the purpose served.

Accordingly, requirements for tensile strength and ductility, varying with the nature of the work and its intended cost, have for some time been demanded, the pieces for test being generally small and of conventional, but by no means uniform, pattern. In a sense, the results so obtained may be considered as gauging the intrinsic quality of the material, so that they are frequently deemed as affording a measure of its fitness for the other principal stresses of compression and shearing, especially as direct tests of the corresponding resistances are more elaborate and costly. The tensile test has thus become the chief, and in some cases the only, measure of quality, and many machines designed to subject pieces of various sizes and proportions to more or less accurately-gauged tensile stress have been constructed and are in use.

In compression, the results obtained from small pieces bear such an uncertain relation to the resistance of large pieces, and the tests require such care and accuracy, that such tests are not in general use, except perhaps for the materials of masonry.

In shearing or torsion the relation of resistance to that under tension is better known and more definite, so that the sufficiency of the latter test is more apparent. In the case of rivets, however, especially of steel, subjected to combined and frequently high initial stresses, it often becomes necessary to test them under, as near as may be, the conditions of practice.

When metal is to be flanged or bent cold or hot, or suddenly cooled from a heated state, corresponding tests, developing extreme stress, are frequently made, both in order to insure freedom from failure under treatment, and sufficiency of strength in the final condition.

A complete system of commercial small tests for metal structures consists therefore of—

(1) The tensile test, with requirements for ultimate tensile strength and final elongation or ductility—sometimes also conceived to be measured by the reduction of area—and in some cases, for the refined qualities of elastic limit and modulus of elasticity, the latter the measure of stiffness.

(2) For rivets, shearing tests approximating to the conditions of practice; and, incidentally, tensile tests as a general measure of quality.

(3) Hot or cold bending tests, or both.

(4) Tests for hardening quality on rapid cooling, sometimes, though erroneously, called "temper tests," but better known as "quenching tests."

Any or all of these tests may be carried out on a greater or less number of specimens, with corresponding representative value.

A variety of other tests has been proposed, and some are in more or less extended use. Such are tests of the change of condition due to punching and shearing, transverse tests for rolled beams, direct torsional tests, tests for wearing quality, and the well-known impact or "drop" test for rails.

The above system of tests has never, we believe, been applied to other material than mild steel, though the tests under each heading have been separately used for a variety of materials. Owing to the irregularity of this metal, as produced by the best makers, but also largely to in-

experience in its treatment, in the early stages of its manufacture and use, mild steel was much more elaborately tested than the iron which it replaced, and especially so for ships and marine boilers. When adopted for these constructions, the various governments and marine insurance societies using it or sanctioning its use, after elaborate preliminary tests, exacted more or less rigid requirements of the nature above described; and, while in some cases they have been somewhat relaxed, they are still very generally demanded and are frequently extended. The requirements of the French navy, the first to use mild steel extensively for ship construction, are given in the Appendix, together with those of the British admiralty and the various insurance registries, and have been already discussed. The experience with the material in this country in boiler, bridge, and ship construction, prior to the adoption of mild steel for the hulls of ships for the United States Navy, has been considered in the Introduction, while the considerations governing the requirements adopted by the Department, with their subsequent modifications, the chief features in the production of steel made under the Board's supervision, with the results in detail and summary, have been given at length.

Much of the success of testing as a guide to construction depends upon the details of the work. Different men with different methods will show very different results from the same material. In order to make the results obtained at different works directly comparable and of standard value, it was therefore necessary to specify the exact method of testing, and leave as little as possible to accident or the individual judgment of the inspector, the disagreeable necessity for which so often arises in most inspection. The system of tests, besides insuring the desired quality of material, has also produced information of theoretical value. We have spoken of commercial tests, or tests on a commercial and comparatively inexpensive basis, as distinguished from scientific tests made purely for purposes of investigation. The possible useful application of the results of commercial testing to the solution of certain problems of great theoretical importance, always within the limits of the essential nature of each test, is advanced in this report from certain results of great theoretical interest to be hereafter considered. The very large amount of commercial testing done as compared with the relatively limited extent of testing for scientific inquiry constitutes in itself a great advantage and emphasizes the desirability of obtaining the maximum of information from the tests commonly made. Besides which, there are so many conflicting causes governing the behavior of metals, that numbers of tests are always necessary for a fair idea of average or extremes of any one quality.

THE TENSILE TEST.

Presupposing the general use of machines accurately gauging the load and under reasonable control, the various forms of specimen and methods of testing in use, with their consequent effect on both tensile strength and ductility, render it necessary in each case to specify accurately the conditions of test. As yet the results of any one system are not directly comparable with those of any other. The necessity, from an engineering point of view, of standardizing the test piece and the method of test is very generally recognized, but the loss of value of the tests already made on any system to be discarded, and the lack of facilities in many places for carrying out tests on any of the systems most generally favored by those who have studied the subject, have so far prevented it.

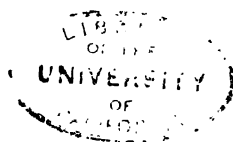
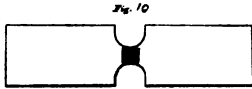
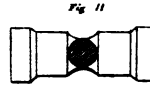


Plate VII.

(1). Groove Form.



*U.S. Supervising Inspectors.
9/8" Plate.*



*U.S. Board on Testing Iron, Steel, &c.
(experimental form)*

(2). Short Filletted Form.

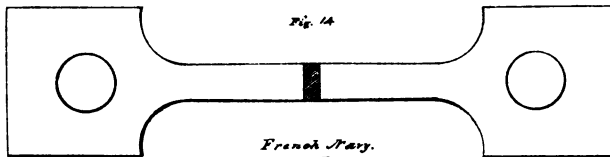


*Pennsylvania and other Railroads.
9/8" Plate.*

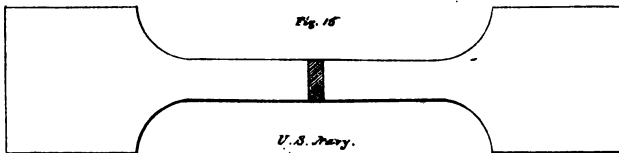


*Ordnance.
(Sir J. Whitworth.)*

(4). Long Filletted Form.



*French Navy.
15 mm Plate.*



*U.S. Navy.
1/2" Plate.*

Test pieces.—The principal forms of test piece which are or have been, used in this country are—

(1) The groove form (Figs. 10 and 11), both flat and round, drilled or rimed out for the former and turned out for the latter. The only result generally desired from this test is the tensile strength, though the fractured area is sometimes obtained, and the ductility arbitrarily measured on an original length of one inch laid off equally on each side of the least width. This form of specimen has the advantage of being easily taken from small pieces, and, for materials of small ductility, the value of the tensile strength so obtained is practically correct. For ductile materials it gives much higher tensile strength and area of fractured section than long parallel-sided pieces, though the amount of the difference does not seem to lie altogether in the ductility. As so used for plates of wrought iron and the mild steels it is sometimes called the "marine test," presumably from its use in testing ship and boiler plate. It doubtless owes its very general use to the ease and cheapness of preparing specimens for test.

(2) The short filleted form (Figs. 12 and 13), both flat and round, as given for the Pennsylvania and other railroads, and very generally used for ordnance purposes.* Like the preceding, it has the advantage of being easily taken from comparatively small pieces. Both tensile strength and fractured area for ductile material are much nearer the results from long pieces than in the groove form and more uniform, but are still too high. The ductility is somewhat arbitrary, in that the measured length includes the short end fillets, which are in a different condition of stress from the straight portion. Being very largely dependent on the proportions of the test piece, the ductility results from these specimens always read very high, especially for the softer materials. This form is cheaper to fashion than the long filleted form, which is perhaps the only excuse for its use in testing boiler material.

(3) The straight-sided form, of any length and any cross-section, provided it be uniform along the length, and either planed out or in condition as finished at the rolls or under the hammer. As planed out on the edges, it is in very general use among bridge engineers for plates and shapes of soft metal, and in the rough-finished state is much used in steel works for grading the metal.

In many respects this is the very best form of test piece, involving small cost to fashion, and allowing each portion of the measured length to be subjected to the same stress and equally free to strain or change its form. About its only disadvantage is the danger of breaking in the grips, a real source of trouble with hard steels, but which can only occur with soft steels in case of malformation of test piece or lack of homogeneity in the material; and if the first be true to any extent, the specimen is not suitable for test. It is worthy of remark that unless the test is affected by one or other of these causes, soft material shows a very strong tendency to break in the middle of the length, and will never break in the grips.

(4) The long filleted form (Figs. 14 and 15), generally adopted, in a length of 8 inches between fillets, for ship purposes. The history of this form is about as follows:

In the first lever machines, before the use of wedge or friction grips, the most convenient way of applying stress was by a pin and hole connection (Fig. 14), which plainly necessitated a spreading of the ends.

* It may be remarked that the results of Sir J. Whitworth's famous fluid-compressed steel are always from a test piece of this kind.

In some cases the ends were further supported by welding or riveting on additional thicknesses. Kirkaldy's early results were so obtained, and the method is still used. When the French navy commenced using mild steel, they adopted this form for the above reason, and the English admiralty officers, after investigating the French system and methods of tests, adopted the same form, and, as near as may be, the same dimensions, for the sole purpose of obtaining uniformity. Thence it came into general use, until the mass of results obtained renders it inexpedient to make a change. Of course it has the advantage that the piece cannot break in the grips unless very lacking in homogeneity.

Six, ten, and twelve inch lengths between fillets are sometimes used, but no very satisfactory formula has been devised for reducing the results to a basis of the same length or to that of any of the other forms.

In using comparatively long straight-sided test pieces, it is necessary to carefully examine them, and measurements should be made in several places along the length in order to guard against an appreciable defect of area at any point, thereby causing only local stretching with consequent small final elongation as measured for the whole length, as well as an error in the record of stress proportionate to such defect of area. This is particularly necessary where there are minimum requirements for individual pieces.

Table XIV.* shows the various proportions of round test pieces (other than the grooved form) in general use in this country and in Europe, and illustrates the different ductilities to be obtained from the same piece of mild-steel in different forms. The difference of tensile strength would also be appreciable in some cases, but there is not sufficient information on the point for accurate comparison.

Table XV.* gives the dimensions of the various flat test pieces in general use.

* Much of the information in both tables is taken from a recent paper before the British Institution of Civil Engineers on "The Adoption of Standard Forms of Test Pieces for Bars and Plates," by William Hackney, B. Sc., Assoc. M. Inst. C. E.

TABLE XIV.

Engineer or administration using test piece.	Authority.	Length.	Diameter.	Ratio of diameter to length.	Estimated ultimate strength of same sample of mild steel if cut into a test piece of each portion.
Sir Joseph Whitworth, Bart., M. Inst. C. E. Woolwich Arsenal, test pieces used for— Steel Wrought iron Cast iron	Minutes of Proceedings Inst. C. E., vol. xlii, p. 107 { Colonel Maitland, Superintendent of the Royal Gun Factories (private letter, August 26, 1881). Tests of Bessemer iron, published at the Paris Exhibition, 1878. (Les Métaux, par H. Lebaubeur, Paris, 1878, p. 112.) Tests published at the Vienna Exhibition, 1873. (On certain matters affecting the use of steel. By E. Marché, Paris. Journal of the Iron and Steel Institute, 1873, p. 472.) P. Everet, Mémoires de la Société des Ingénieurs civils, 1877, p. 329. (Minutes of Proceedings Inst. C. E., vol. xli, p. 360.) E. Marché, <i>loc. cit.</i>	<i>Inches.</i> 2 2 2 2 <i>mm.</i> 150	<i>Inches.</i> 0.798 0.533 0.754 1.066 <i>mm.</i> 25	1 to 2.506 1 to 3.75 1 to 2.65 1 to 1.88 1 to 6.00	<i>Per cent.</i> 44.5 37.5 43.5 52.0 32.0
Austro-Hungarian State Railway		100	16	1 to 6.25	31.5
Usine du Creusot		100	15	1 to 6.6	31.0
Compagnie de Terre-Noire		100	15	1 to 6.6	31.0
Société John Cockerill, Seraing, Belgium		150	23 to 20	{ 1 to 6.8 1 to 7.5 1 to 9.6 }	{ 30.9 to 30.2 30.9 to 30.2 28.5 to 30.2 }
Professor K. H. Thurston	Report of Board on Testing, &c., 1881, vol. ii, pp. 293-396	<i>Inches.</i> 6	{ 0.625 and 0.798 <i>mm.</i>	{ 1 to 7.52 1 to 8.0 1 to 10.0 1 to 10.0 }	{ 29.8 28.2 28.2 27.9 to 27.2 }
Colonel Rosset	Régie d'Artillerie, May, 1875, p. 124. (Minutes of Proceedings Inst. C. E., vol. xliii, p. 417.) Les Métaux, par H. Lebaubeur, p. 72	<i>mm.</i> 200	25	1 to 8.0	29.8
Compagnie de Terre-Noire	The dephosphorization of iron in the Bessemer Converter. (Journal of the Iron and Steel Institute, vol. i, 1880, p. 57.)	200 150	20 15	1 to 10.0 1 to 10.0	28.2 28.2
R. Pink Horde, Westphalia	British Association Report, 1890	<i>Inches.</i> 8	{ 0.772 to 0.69 }	{ 1 to 10.36 1 to 11.59 }	{ 27.9 to 27.2 27.9 to 27.2 }
Sir W. Fairbairn		<i>See feet.</i> 5			
K. Styffe	Iron and Steel, by K. Styffe. Translated by C. P. Sandberg, p. 16	<i>Inches.</i> 8	0.750 { 0.500 to 0.575 }	1 to 10.97 1 to 9.14 1 to 16	27.7 29.0 to 28.3 1 to 16
Cambria Iron Works. Test pieces for steel					
United States Navy Department. Test pieces for steel-rivet bar.	Present report	8			

TABLE XIV—Continued.

Engineer or administration using test piece.	Authority.	Length.	Diameter.	Ratio of diameter to length.	Estimated ultimate strength of same sample of mild steel if cut into a test piece of each proportion.
		Inches.	Inch. $\left\{ \begin{array}{l} 0.625 \\ \text{to} \\ 0.750 \end{array} \right.$	$\left\{ \begin{array}{l} 1 \text{ to } 2.66 \\ \text{to} \\ 1 \text{ to } 3.2 \end{array} \right.$	Per cent. $\left\{ \begin{array}{l} 43.5 \text{ to } 40.5 \end{array} \right.$
Pennsylvania Railroad *	Various specifications.....	2			

* In the test pieces used by Sir J. Whitworth and the Pennsylvania Railroad, the measured length of 2 inches includes sharp fillets at the ends (in the Pennsylvania Railroad to $\frac{1}{4}$ -inch radii) so that their comparative extensions are somewhat less than as given in the table. Thus Sir J. Whitworth's should probably read 40.5, and the Pennsylvania Railroad's 39.0 to 38.0 per cent.

TABLE XV.

Engineer or administration using test strip.	Authority.	Length.	Width.	Ratio of width to length.
London and Northwestern Railway Company, Crewe Works.	Extended report on steel for ship-building. (Lloyd's Register of British and Foreign Shipping, No. 391, 6th December, 1877, p. 7.)	2"	(f)	
Sheerness and Chatham Dockyards. Tests of steel and iron boiler plates made at Sheerness in 1875, and at Chatham in 1879.	On the comparative endurance of iron and mild steel when exposed to corrosive influences, by D. Phillips. (Minutes of Proceedings, Inst. C. E., vol. lxx, p. 96.)	4"	1.51" to 1.5"	$\left\{ \begin{array}{l} 1 \text{ to } 2.6 \\ \text{to} \\ 1 \text{ to } 2.65 \\ \text{to} \\ 1 \text{ to } 1.0 \end{array} \right.$
Mr. W. Parker	On the use of steel for marine boilers. (Transactions of the Institution of Naval Architects, vol. xix, 1876, p. 175.)	4"	4" to 2.7"	$\left\{ \begin{array}{l} 1 \text{ to } 1.5 \\ \text{to} \\ 1 \text{ to } 5 \end{array} \right.$
Usine du Creusot.	Prof. L. Gruner (Private Letter, December 17, 1882)	100mm 200mm	20mm 20mm	$\left\{ \begin{array}{l} 1 \text{ to } 5 \\ \text{to} \\ 1 \text{ to } 10 \end{array} \right.$
The majority of French railway companies. Test strips for boiler-plates.	do			
Ministère de la Marine Française. Circular dated May 10, 1876.	Sur les Expériences de Résistance des Matériaux en France et aux États Unis, par H. Tresca. (Annales du Conservatoire des Arts et Métiers, 1877.)	200mm	(Thickness. Width of strip.) $\left\{ \begin{array}{l} \text{Under } 5\text{mm} \\ 5 \text{ to } 18\text{mm} \\ 18\text{mm} \text{ and} \\ \text{above.} \end{array} \right.$ $\left\{ \begin{array}{l} 20\text{mm} \\ 30\text{mm} \\ \text{Thickness of} \\ \text{the plate.} \end{array} \right.$ 70.2mm	$\left\{ \begin{array}{l} 1 \text{ to } 6.6 \\ \text{to} \\ 1 \text{ to } 10 \end{array} \right.$
Jern Kontoret, Stockholm	Expériences de force et de traction sur des tôles Suédoises produites par des procédés divers, faites aux frais du Comptoir des Forges (Jern Kontoret), Stockholm, 1878.	200mm		1 to 2.85
British Admiralty	Steel for ship-building. By Henry H. West. (Transactions of the Institution of Naval Architects, 1880.)	8"	(f)	
Lloyd's Register of British and Foreign Shipping.	Extended report, &c.	8"	(f)	
Mr. D. Adamson.	On the mechanical and other properties of iron and mild steel. (Journal of the Iron and Steel Institute, vol. ii, 1878, p. 394.)	10"	(f)	
German Railway Union. Tests made between 1876 and 1878.	Organ für die Fortschritte des Eisenbahnwesens, Supplement, 1880. (Minutes of Proceedings, Inst. C. E., vol. lxx, p. 439.)	400mm	25mm	1 to 16
Albert F. Hill	Steel in construction. By Albert F. Hill. (Engineer's Society of Western Pennsylvania Engineering News (New York) May 15, 1880, p. 170.)	For $\frac{3}{4}$ " plate, 18" For $\frac{1}{2}$ " plate, 15" For $\frac{1}{4}$ " plate, 12"	14" 14" 1"	$\left\{ \begin{array}{l} 1 \text{ to } 12 \\ \text{to} \\ 1 \text{ to } 12 \\ \text{to} \\ 1 \text{ to } 6 \end{array} \right.$
Mr. D. Kirkaldy. Usual standard form for plate specimens.	Experimental inquiry into the mechanical properties of Fagersta steel. London, 1873, p. 25.			
Cambria Iron Works. Test pieces for steel	United States naval inspector of material	8"	$\frac{3}{4}$ " and 1" \square	$\left\{ \begin{array}{l} 1 \text{ to } 8 \\ \text{to} \\ 1 \text{ to } 10.67 \\ \text{to} \\ 1 \text{ to } 6.4 \end{array} \right.$
United States Navy Department. Test strips for steel plates and shapes.	Present report.	8"	1" to 1.25"	$\left\{ \begin{array}{l} 1 \text{ to } 8 \\ \text{to} \\ 1 \text{ to } 6.4 \end{array} \right.$
Pennsylvania Railroad.	Various specifications.	2" (incl. $\frac{1}{4}$ " fillet).	(Thickness. Width.) $\left\{ \begin{array}{l} \text{Thickness.} \\ \frac{1}{4}" \text{ or less.} \\ \frac{1}{4}" \text{ to } 1" \end{array} \right.$ $\left\{ \begin{array}{l} \text{Width.} \\ 1\frac{1}{4}" \\ \frac{1}{4}" \end{array} \right.$	$\left\{ \begin{array}{l} 1 \text{ to } 1.33 \\ \text{to} \\ 1 \text{ to } 2.66 \end{array} \right.$

THE LAW OF PROPORTION.

The most remarkable set of experiments as to the influence of form are those made by M. J. Barba, chief engineer of the great French steel works of MM. Schneider, at Creusot, from which he deduces a law of symmetry, expressing the identity of the percentages of ultimate stretching in test pieces of the same metal and similar in form.*

We reproduce the following tabular information taken from the paper on "The Adoption of Standard Forms of Test Pieces for Bars and Plates," before referred to, as giving the chief results of his experiments:

The test pieces used were of the pattern shown in Fig. 16.

Fig. 16.

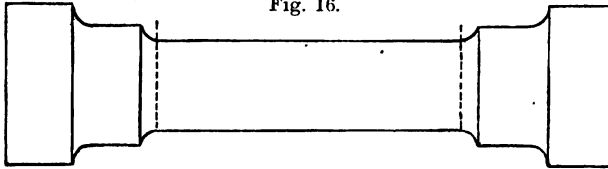


TABLE XVI.

A billet of extra soft steel was hammered to an octagon of 80 by 80 millimeters, rolled to a bar 30 millimeters in diameter, and very carefully annealed. Three test pieces were then cut from it in the lathe and broken, with the following results:

Numbers of test bars.	Diameters.	Lengths between datum points.	Limit of elasticity.	Breaking load.	Total stretch.	Stretch.
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Kil. per sq. millimeter.</i>	<i>Kil. per sq. millimeter.</i>	<i>Millimeters.</i>	<i>Per cent.</i>
1.....	20	200	24.8	37.6	62.0	31.0
2.....	10	100	24.7	36.8	30.5	30.5
3.....	5	50	24.8	37.7	15.7	31.4

TABLE XVII.

Experiments repeated on test pieces of two harder grades of steel, cut from bars rolled to 40 millimeters in diameter, annealed, and turned down to same proportion of diameter to length.

(a) MILD STEEL.

Numbers of test bars.	Diameters.	Lengths between datum points.	Ratio of diameter to length.	Limit of elasticity.	Breaking load.	Final area of original area.	Total stretch between datum points.	Stretch.
	<i>Millimeters.</i>	<i>Millimeters.</i>		<i>Kil. per sq. millimeter.</i>	<i>Kil. per sq. millimeter.</i>	<i>Per cent.</i>	<i>Millimeters.</i>	<i>Per cent.</i>
1.....	6.90	50	} 1 to 7.24 {	24.0	42.2	30.7	16.4	32.8
2.....	10.35	75		24.0	42.0	31.0	24.9	33.2
3.....	13.80	100		24.2	42.1	30.3	33.0	33.0
4.....	17.25	125		23.9	41.7	31.4	41.8	33.5
5.....	20.70	150		23.8	41.6	30.8	50.4	33.6
6.....	24.15	175		24.0	40.9	30.3	58.0	33.2
7.....	27.60	200		24.1	40.0	31.2	66.0	33.0
8.....	31.05	225		24.0	39.6	30.5	76.5	34.0
Means.....				24.0	41.3	30.8		33.3

* "Résistance des Matériaux. Epreuves de résistance à la traction. Étude sur les allongements des métaux après rupture." Par J. Barba. Mémoires de la Société des Ingénieurs Civils, 1880, Part I, p. 682.

TABLE XVII.—Continued.

(b) HARD STEEL.

Numbers of test parts.	Diameters.	Lengths between datum points.	Ratio of diameter to length.	Limit of elasticity.	Breaking load.	Final area of original area.	Total stretch between datum points.	Stretch.
	<i>Millimeters.</i>	<i>Millimeters.</i>		<i>Kil. per sq. millimeters.</i>	<i>Kil. per sq. millimeters.</i>	<i>Per cent.</i>	<i>Millimeters.</i>	<i>Per cent.</i>
1.....	6.90	50	1 to 7.24	32.7	64.8	63.5	10.0	20.0
2.....	10.35	75		36.6	64.9	62.0	14.1	18.8
3.....	13.80	100		35.7	63.8	62.6	18.2	18.2
4.....	17.25	125		38.0	63.3	61.6	22.7	18.1
5.....	20.70	150		40.6	63.5	63.2	27.0	18.0
6.....	24.15	175		38.1	62.0	64.2	31.7	18.1
7.....	27.60	200		38.1	63.2	65.6	39.0	19.5
8.....	31.05	225		Not tested.				
Means				37.1	63.6	63.9		18.6

When, on the other hand, the test pieces used are either of different diameters and equal lengths, or of different lengths and equal diameters, the percentages of ultimate stretching, when portions of the same bar are tested, are very different.

M. Barba gives the following results (Tables XVIII. and XIX.):

TABLE XVIII.—Test pieces of equal length between the datum points, but varying from 5 to 20 millimeters in diameter.

(a) SOFT STEEL.

(Pieces cut from the same bar of extra soft steel as that used in the experiments of which the results are given in Table XVI.)

Numbers of test bars.	Diameters.	Length between datum points.	Limit of elasticity.	Breaking load.	Total stretch between datum points.	Stretch.
	<i>Millimeters.</i>	<i>Millimeters.</i>	<i>Kil. per sq. millimeters.</i>	<i>Kil. per sq. millimeter.</i>	<i>Millimeters.</i>	<i>Per cent.</i>
1.....	20	100	25.0	37.0	37.5	37.5
2.....	10	100	24.8	36.9	30.2	30.2
3.....	5	100	25.2	37.6	25.0	25.0

(b) HALF-HARD STEEL.

1.....	20	100	34.5	59.3	25.9	25.9
2.....	10	100	33.5	59.4	21.0	21.0
3.....	5	100	33.0	60.0	17.0	17.0

TABLE XIX.—Ten test pieces of equal diameter and similar in form at the ends, but varying from 50 to 500 millimeters in length between the datum points.

Numbers of test pieces.	Dimensions.		Resistance.		
	Diameter.	Lengths.	Limit of elasticity.	Breaking load.	Contraction of area.
1 to 10.....	<i>Millimeters.</i> 17.2	<i>Millimeters.</i> 50 to 500	<i>Kil. per sq. millimeter.</i> 23.7	<i>Kil. per sq. millimeter.</i> 37.0	<i>Per cent.</i> 68.3

ULTIMATE STRETCHING OF EACH TEST PIECE.

[The lengths of the test pieces between the datum points are given in millimeters.]

	Total millimeters.	Per cent.
50 (=2.91 diameters)	21.0	42.0
100 (=5.81 diameters)	32.0	32.0
150 (=8.72 diameters)	44.0	29.3
200 (=11.6 diameters)	54.5	27.2
250 (=14.5 diameters)	66.5	26.6
300 (=17.4 diameters)	78.0	26.0
350 (=20.3 diameters)	88.0	25.1
400 (=23.8 diameters)	100.0	25.0
450 (=26.2 diameters)	112.0	24.9
500 (=29.1 diameters)	124.1	24.8

M. Barba quotes the experiments, Table XX., to show that the law of similarity, as he calls it—that is, the law that test pieces similar in form give the same percentage of ultimate stretching, whatever their size may be—prevails equally in flat and in cylindrical test pieces, if cut from the same bar and not reduced to the different sizes by hammering or rolling.

TABLE XX.

Numbers of test pieces.	Dimensions of test pieces.				Resistance.		Ultimate stretching.	
	Widths.	Thick- nesses.	Ratio of width to thick- ness.	Length between datum points.	Limit of elasticity.	Breaking load.	Total stretch between datum points.	Stretch.
	Milli- meters.	Milli- meters.		Milli- meters.	Kil. per sq. millimeter.	Kil. per sq. millimeter.	Milli- meters.	Per cent.
1.....	20	5	} 4 to 1 {	50	16.8	37.2	19.5	39
2.....	40	10		100	17.1	38.2	39.0	39
3.....	60	15		150	20.7	38.9	58.5	39
Means					18.2	37.4		39

Table XXI., also from M. Barba's paper, gives the percentages of ultimate stretching of test strips of steel plate of equal length and thickness but differing in width.

TABLE XXI.

Numbers of test strips.	Dimensions of test strips.				Resistance.		Total stretching.	
	Widths.	Thick- nesses.	Ratio between width and thick- ness.	Length between datum points.	Limit of elasticity.	Breaking load.	Measured on a length of—	
	Milli- meters.	Milli- meters.		Milli- meters.	Kil. per sq. millimeter.	Kil. per sq. millimeter.	50 milli- meters.	100 milli- meters.
1.....	10	10	1	100	24.8	38.4	18.8	31.0
2.....	20	10	2	100	24.6	40.1	22.5	34.0
3.....	30	10	3	100	25.4	39.4	24.0	35.0
4.....	40	10	4	100	25.0	39.8	26.0	37.2
5.....	50	10	5	100	24.6	38.1	28.0	39.0
6.....	60	10	6	100	24.9	37.7	30.5	40.8
7.....	70	10	7	100	24.8	37.8	28.5	38.5
8.....	80	10	8	100	23.5	38.4	28.0	34.5
Means					24.7	38.7	25.5	36.2

This seems to show that, for this hardness of steel and for plates 10 millimeters thick, when the ratio of width to thickness is as 6 to 1 the maximum elongation takes place.

Examination of this table, however, shows that the increase of ductility follows very nearly the law for rounds, if the effective diameter of the flat be taken as the mean of its width and thickness, until a width of 60 millimeters is reached; it is very probable that the ductility of the wider pieces was influenced by the method of holding the ends. Indeed it is very difficult to devise a grip for short wide pieces of plate which shall at the same time equally distribute the stress and not constrain the reduction and consequently the stretch.

As further bearing upon the accuracy of the comparison of results from flats and rounds by taking the mean of the two sectional dimensions of the flat for its effective diameter, and affording direct information as to the sufficiency of a standard test piece, say a $\frac{3}{4}$ -inch round, from which the results in other forms can be, at least approximately, deduced, the following Table XXII. is given, being a comparison of the results of a number of heats of Cambria steel as flats and as rounds tested on the same machine. The column of elastic ratios is given as constituting a measure of physical condition, which, upon the average, is seen to be identical for the material in the two forms. Heat 5585 is omitted from the average, the differences being beyond the limit of error; the flat pieces showed evidence of fine lamination and were probably taken from too near the top of the ingot. The result is seen to be slightly higher elastic limit, ultimate tensile strength, final elongation, and reduction of area from the flats. With the exception of the reduction of area, the method of measuring which was somewhat uncertain and inaccurate, the results are very much as would be expected from the experiments on the effect of length of test piece to be later described. The higher tensile strength of the flats is also notable as corroborating the results of these experiments. As a conclusion from this comparison, it may be stated that the results of this material as $\frac{7}{8}$ -inch rounds would probably be practically identical with those of the $\frac{7}{8}$ -inch flats; and it appears probable that the effective diameters as described give a sufficiently accurate basis of comparison in all ordinary cases.

TABLE XXII.—Comparison of results of tensile tests of the same material as flats and as rounds.

Heat.	Shape.	Size of piece from which test piece was taken.	Effective diameter.	Ratio of measured length to effective diameter.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Elastic ratio.	Final elongation.	Final area.	Appearance of fracture.
		Inches.	Ins.		Pounds.	Pounds.	P. ct.	P. ct.	P. ct.	
5565	Flat	6 by $\frac{7}{8}$.8365	9.563	44,030	66,469	66.24	24.43	54.68	Silky. Silky; piece somewhat pitted.
	Round	$\frac{3}{4}$	.7435	10.760	43,135	64,555	66.84	26.05	50.70
	Difference ..				895	1,914	.60	1.62	3.98	
5567	Flat	6 by $\frac{7}{8}$.8459	9.453	41,576	65,475	63.50	25.25	50.44	Silky. Do.
	Round	$\frac{3}{4}$	.7475	10.700	42,630	63,205	65.38	25.20	52.25
	Difference ..				1,054	270	1.88	.05	1.81	
5569	Flat	6 by $\frac{7}{8}$.8440	9.479	37,850	60,839	62.22	28.13	51.01	Silky. Do.
	Round	$\frac{3}{4}$	.7420	10.780	38,390	59,550	64.47	27.90	47.10
	Difference ..				540	1,289	2.25	.23	3.91	
5579	Flat	6 by $\frac{7}{8}$.8345	95.86	46,515	67,100	69.32	24.18	55.09	Silky. Silky and crystalline.
	Round	$\frac{3}{4}$	.7410	108.00	42,090	65,620	64.15	23.80	60.20
	Difference ..				4,425	1,480	5.17	.38	5.11	

TABLE XXII.—Comparison of results of tensile tests of the same materials as flats and as rounds—Continued.

Heat.	Shape.	Size of piece from which test piece was taken.	Effective diameter.	Ratio of measured length to effective diameter.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Elastic ratio.	Final elongation.	Final area.	Appearance of fracture.
5580	Flat	Inches. 6 by $\frac{1}{8}$	Ins. .8510	9.402	Pounds. 38,406	Pounds 61,779	P. ct. 62.17	P. ct. 26.60	P. ct. 51.04	Silky. Do.
	Round .....		.7480	10.700	41,530	62,690	66.25	24.30	57.60
	Difference				3,124	811	4.08	2.30	6.56	
5581	Flat	6 by $\frac{1}{8}$.8456	9.462	38,892	61,573	63.16	27.20	47.09	Silky. Do.
	Round .....		.7425	10.775	39,490	61,770	63.93	24.80	52.10
	Difference				598	197	.77	2.40	5.01	
5583	Flat	6 by $\frac{1}{8}$.8449	9.470	45,090	68,120	66.20	24.75	55.05	Silky. Do.
	Round .....		.7450	10.740	42,210	67,330	62.70	22.60	58.00
	Difference				2,880	790	3.50	2.15	3.55	
5585	Flat	6 by $\frac{1}{8}$.8423	9.498	34,020	58,734	57.94	26.85	52.70	Silky. Do.
	Round .....		.7475	10.700	43,860	62,330	70.38	25.90	47.50
	Difference				9,840	3,596	12.44	.95	5.20	
5586	Flat	6 by $\frac{1}{8}$.8424	9.497	42,680	68,856	61.09	25.50	53.23	Silky. Do.
	Round .....		.7420	10.780	41,620	67,070	62.05	24.80	46.70
	Difference				1,060	1,786	.06	.70	6.53	

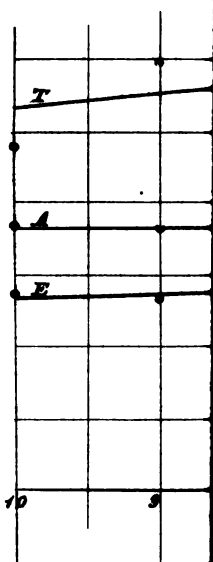
AVERAGE.

[Exclusive of heat 5585.]

8	Flat	6 by $\frac{1}{8}$	.....	9.490	41,880	65,026	64.41	25.75	52.20	
8	Round .....		.....	10.754	41,387	64,224	64.44	24.93	53.16	
	Difference .....		.....		403	802	.....	.82	.96	

The extreme case of the groove form giving much higher values for tensile strength, and incidentally for final area, and the natural probability that these effects would follow a regular law, induced the Board to make a series of experiments to determine the nature of the effect of change of length. Accordingly, the part numbered 10 of annealed plate 678 W, originally intended for the Chicago's boilers, and which had been cut up for other tests (p. 163), being considered sufficiently homogeneous, test pieces numbered 1 to 24, consecutively, were removed, as shown, Fig. 20, and variously shaped for test, the results being given in Table XXIII. Plate VIII. shows its graphic representation, in which the groove form is taken as the zero of length. The final elongation for the groove form is obtained by subtracting unity from the reciprocal of the ratio of fractured to original area and writing the decimal as per cent., and represents, therefore, the differential extension at the bottom of the groove. The dotted terminal line is in accordance with the experiments, but the results for final area in the grooved form being in this case believed to be abnormal, the solid lines show the results of an average of many tests in groove form from this plate.

The curves show at a glance the nature and probable amount of difference in results from test pieces of various proportions in use for boiler plate. Thus this plate tested by the United States Supervising Inspector would give about 63,000 pounds tensile strength and 50 per





cent. reduction; tested for the Pennsylvania Railroad, it would show about 56,500 pounds, with 36 per cent. elongation; while, as tested under this inspection, the result should be 55,700 pounds, with 27.9 per cent. elongation. The difficulty of the steel manufacturer in working to such discrepant specifications is evident.

An unexpected decrease of tensile strength for lengths greater than about 3 inches is a feature of the corresponding curve. The cause of this is naturally looked for in the condition of the plate, but on referring to Fig. 20, it is seen that while Nos. 17 and 18 are near the edge of the plate, Nos. 19 and 20 are in the center and adjacent to Nos. 3 and 4, and that Nos. 23 and 24, the 10-inch lengths, are adjacent to Nos. 7 and 8, the 2½-inch lengths, the difference of tensile strength being 1,450 pounds. This result requires corroboration before being accepted.

TABLE XXIII.—Showing effect of length of test piece.

ANNEALED BOILER PLATE OF CHESTER STEEL.

Original length between witness marks.	Number of piece.	Original width.	Original thickness.	Original sectional area.	Ultimate tensile strength per square inch.	Final elongation.	Final area.	Average tensile strength per square inch.	Average elongation.	Average final area.
Inches.		Inches.	Ins.	Sq. ins.	Pounds	Pr. ct.	Pr. ct.	Pounds.	Pr. ct.	Pr. ct.
Groove	1	0.990	.660	.6534	63,330	41.0	47.0			
	2	0.995	.660	.6567	62,800	40.0	45.0	63,065	40.5	46.0
1½	3	0.990	.665	.6583	56,660	49.0	44.0			
	4	0.990	.665	.6583	56,660	49.0	43.0	56,660	49.0	43.5
2	5	1.021	.665	.6790	56,400	42.0	43.0			
	6	1.021	.661	.6750	56,800	46.0	40.0	56,600	44.0	41.5
2½	7	0.968	.668	.6466	50,200	40.0	39.0			
	8	0.968	.668	.6466	50,200	40.0	41.0	56,200	40.0	40.0
3	9	1.015	.660	.6700	56,400	38.0	39.0			
	10	1.015	.660	.6700	56,400	38.0	40.0	56,400	38.0	39.5
4	11	0.980	.655	.6420	56,300	34.0	39.0			
	12	0.980	.660	.6470	56,100	35.0	37.0	56,200	34.5	38.0
5	13	0.970	.650	.6300	56,300	33.0	37.0			
	14	0.970	.650	.6300	56,500	33.0	37.0	56,445	33.0	37.0
6	15	1.037	.650	.6740	55,700	29.0	36.7			
	16	1.037	.647	.6710	55,700	30.0	37.0	55,700	29.5	36.9
7	17	1.000	.645	.6450	56,000	28.5	39.0			
	18	1.000	.642	.6420	56,500	28.5	40.0	56,250	28.5	39.5
8	19	0.933	.664	.6195	55,200	27.4	40.0			
	20	0.933	.664	.6195	55,200	28.4	37.0	55,200	27.9	38.5
9	21	0.962	.655	.6301	56,000	28.0	35.0			
	22	0.964	.653	.6295	55,910	25.1	37.8	55,955	26.6	36.4
10	23	1.000	.668	.6630	54,750	27.8	37.7			
	24	1.000	.663	.6630	54,750	27.0	36.0	54,750	27.4	36.8

TENSILE TESTS BY INCREMENTS AND BY CONTINUOUS LOADS.

Next to the form of test piece, the subject most in dispute is the method of applying stress as regards time; that is, whether by regular increments at regular intervals or continuously at approximately uniform speed of ram or screw. It is claimed that in continuous testing both time and power are saved and the capacity of the machine in amount of work correspondingly increased, and this method is accordingly the more generally used, especially in grading steel at the works, while the Board has adopted the method of increments. As a matter of fact, if anything like a complete record of each test is kept, the time taken up in making the necessary calculations for the results of each piece—which, to avoid error, should always be made before commencing to strain the next—even with the various tables used as aids

to calculations, reduces the difference of time to a very small amount, because in testing by increments much of this work can be done while straining the piece. Thus, the modulus of elasticity, the elastic limit, ultimate tensile strength, and extension at tensile limit, can all be recorded by the time the piece breaks, and there remain only the final measurements of elongation and fractured area and the quantities depending on them.

But the cause of the original adoption of the method of increments was in order to obtain, as nearly as may be, uniformity in the method of testing by different inspectors on different machines, in the absence of any conclusive information as to the effect of different methods of testing on the results. These considerations still hold, but the method has been so far modified as to substitute for the five minutes of initial strain one minute, or such other time as may be necessary to measure the initial extension, and, in order to obtain the principal elastic limit, regular increments are only to be applied beyond that stress.

As regards the effect on the results, it is believed that, in general, for this material under increasing stress, marked differences will be caused only by differences in the application of stress very near and beyond the tensile limit. The following considerations lead to this opinion.

It would appear* that as regards capacity for sustaining a stress beyond the elastic limit without increased distortion for a long time, the metals may be divided into two distinct classes: (1) the "iron" class, which will sustain a static load even near its ultimate strength for any length of time without increased distortion, and (2) the "tin" class, which undergoes a gradually increasing distortion under stresses which are only a fraction of those required to break such metals quickly. The difference is due to the existence at such stresses in the latter class of the quality of viscosity to a greater or less degree, and their apparent ultimate strength depends entirely upon the opportunity afforded to flow under the stress, and, therefore, upon the time of action of the load, or each load in breaking by increments.

But it has been shown by Tresca that all sufficiently ductile materials, including steel, presumably harder than the mild quality under consideration, can be brought to the plastic or viscous condition by the proper application of stress, as illustrated in the cold drawing of lead pipes under compression. It is well known that in such a state the strength of such soft steels as we are considering is seriously affected by the opportunity afforded for relief, by flow, of the internal strains produced by drawing out either under compression or tension, for the principal stresses are interchangeable in their effects upon plastic materials. Thus it is within the experience of all wire mills where testing is done that steel wire as fresh drawn is both weaker and less ductile than after several months of rest.

We shall see when considering the extension diagrams (p. 136 *et seq.*), that a condition of flow appears to be reached, probably in most cases, slightly before tensile limit in mild steel, to a varying extent in different heats, and, of course, with different degrees of hardness. It would accordingly appear that the conditions of straining from just before tensile limit up to rupture may slightly affect the apparent ultimate

* See papers before the American Society of Civil Engineers, by Prof. R. H. Thurston entitled, "Note on the Resistance of Materials, as Affected by Flow and by Rapidity of Distortion" (March 1, 1876), and "The Ratio of Set of Metals Subjected to Strain for Considerable Periods of Time." (December 6, 1876.)

strength and to a greater degree the contraction of area and that part of the final extension which is due to the flow of the material while necking. We might expect to find that if, at this time, strain is brought on by a series of jerks as in a common hand-hydraulic machine using one pump, the material is not given time to flow, and the ultimate tensile strength and final area will be higher and final elongation generally lower than with continuous and slowly applied strain. If, however, the jerks are sufficiently rapid from the beginning, that element of the extension which consists of the more or less uniform extension over the whole length may be so much increased as actually to make the final elongation measured on the whole length greater, but the ultimate strength and final area will be larger as before. In ordinary testing the differences cannot be great, and many experiments are necessary to conclusively establish them, but it is seen that such differences as may be observed are probably due to the method of applying strain whether smoothly or by jerks, the ultimate strength and final area being increased by the latter method, provided the material does not exhibit viscosity much below tensile limit, when the time of absolute straining becomes important. The two essential elements of the elongation are differently affected and the combined action becomes one of difference, the figure being higher for very rapid or impulsive application, less for jerky action not sufficiently rapid to be reckoned impulsive, and higher again for smooth, slow application of strain.

Attention is called to the fact that study of extension diagrams, such as those referred to, under these different conditions would throw probably considerable light on the subject, and also on the relative condition of viscosity of different pieces of metal.

It is conceivable, however, that the intrinsic nature of the material may be such that the effects of viscosity may appear for stresses considerably removed from tensile limit. Thus Commander L. A. Beardslee, U. S. N., has observed that one of the softest and most ductile specimens of chain iron tested by him at the Washington navy-yard exhibited a perceptible increase of resistance under rapid extension, as in the "tin" class.

If, indeed, the extension be very rapid or explosive from the beginning, it is conceivable that the time allowed for flow at any one point may be so small that the phenomenon of multiple necking, hereafter mentioned as occurring in as many as three places in a well-shaped piece of mild steel under slow test, may, so to speak, hold for all points, and the piece be drawn out or flow equally all along, thereby exhibiting a very great final extension, though, of course, with comparatively small contraction of area. This phenomenon, in fact, is reported by Col. E. Maitland, R. A., Superintendent of the Royal Gun Factory at Woolwich, England, thus: * "Soft, untempered steel, having in the machine an elongation of 30 per cent.,† had in the drop test an elongation of 38 or 40 per cent.; when tested by gunpowder, the elongation was 45 or 46 per cent.; and with gun-cotton, it actually rose to 60 per cent."

If the rapid or explosive force had been applied only after necking had begun, with appreciable local reduction of area, the effect would have been very different.

Table XXIV. gives the results of some tests made at the Chester Rolling Mills for information as to the effect of ordinary differences of time.

* See discussion on the paper on "The Adoption of Standard Forms of Test Pieces for Bars and Plates."

† The elongations are for the short test pieces given in Table XIV. as in use at Woolwich Arsenal.

The slow tests were made by increments, in accordance with the general method pursued in this inspection. When tensile limit was approached, the machine was run slowly and steadily until fracture, the weights being adjusted so as to practically maintain a balance at all times. In the fast pull the same power was applied throughout, the rapidity of ram near and beyond tensile limit being greater than in the slow test. The results for ductility and final area are somewhat interfered with by laminations in one of the pieces broken by fast pull, the differences for ductility and final area being thereby increased. The results are illustrative of the conclusions above arrived at, the fast pull giving higher strength and less ductility with greater final area. The differences in the results of the slow tests with the grain from the original heat tests, as well as those in the two pieces for heat test, are suggestive of the lack of homogeneity commonly met with in plates.

TABLE XXIV.—Comparison of results of same material by fast and slow tensile tests.

[Heat, 705; carbon, .16 per cent.; mang., .40 per cent.]

ORIGINAL HEAT TEST.

Marks.	Original width.	Original thickness.	Original area.	Ultimate tensile strength per square inch.	Final elongation.	Final area.	Time of test.	Average tensile strength per square inch.	Average final elongation.	Average final area.
	<i>Inches.</i>	<i>Inches.</i>	<i>Sq. ins.</i>	<i>Pounds</i>	<i>Per ct</i>	<i>Per ct.</i>	<i>m. s.</i>	<i>Pounds.</i>	<i>Per ct.</i>	<i>Per ct.</i>
705	1.150	.580	.5909	60,750	25.00	51.00	.....	.....	.....	.....
706	1.135	.535	.6072	62,580	25.70	48.00	.....	.....	.....	.....

SLOW PULL, LENGTHWAYS.

1.—705 G.....	1.011	.530	.5358	59,500	26.0	47.0	.....	.....	.....	.....
2.—705 G.....	1.005	.530	.5326	59,300	28.0	47.0	.....	59,400	27.0	47.0

FAST PULL, LENGTHWAYS.

3.—705 G.....	1.048	.531	.5564	60,020	24.0	*53.0	2 30	....	.....	.....
4.—705 G.....	1.010	.531	.5363	59,660	24.6	42.0	2 30	59,840	24.3	47.5

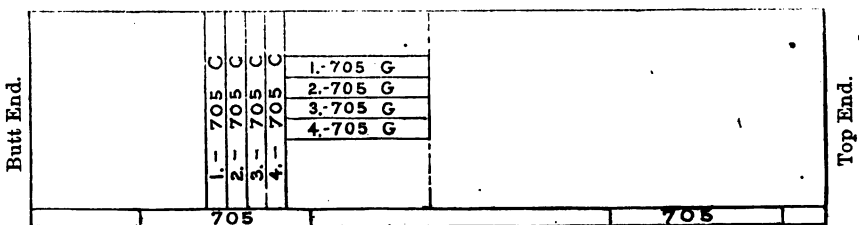
* Piece showed laminations in fracture.

SLOW PULL, CROSSWAYS.

1.—705 C	1.000	.528	.5280	58,090	22.3	47.0	.....	.....	.....	.....
2.—705 C	1.045	.532	.5560	58,900	24.0	47.0	.....	58,995	23.15,	47.0

FAST PULL, CROSSWAYS.

3.-705 C	1.022	.530	.5416	59,630	22.0	50.0	2 30	.....	.....	.....
4.-705 C	1.039	.530	.5501	59,080	21.5	54.0	2 30	59,355	21.75	52.0



	Ultimate tensile strength per square inch.	Final elongation.	Final area.
	<i>Pounds.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Average heat test	61,665	25.35	49.50
Average slow pull	59,198	25.08	47.00
Average fast pull	59,598	23.03	49.75
Difference fast over slow	+400	-2.05	+2.75

Table XXV. shows the mean results of some experiments presented by Mr. William Denny to the Institution of Naval Architects in 1880. The tests were made with a hydraulic machine.

TABLE XXV.

	Ultimate strength per square inch.	Elonga- tion in 8 inches.	Time.
HARD STEEL.	<i>Pounds.</i>	<i>Per cent.</i>	<i>m. s.</i>
Mean of six experiments, plate $\frac{1}{2}$ inch thick...	91,011	11.96	1 30
Mean of six experiments from same plate	89,286	11.48	11 50
SOFT STEEL.			
Mean of two experiments, plate $\frac{1}{2}$ inch thick...	65,296	23.55	1 30
Mean of two experiments from same plate ..	64,176	23.55	4 43
Do.....	64,736	22.7	13 11

It is seen that the very rapid testing gave higher results for ultimate strength and ductility, as would be expected. The contraction of area is not given, but was probably less in the rapid testing.

Table XXVI. gives the results of some experiments on steel similar to that for the cruisers, made at the Cambria Iron Works by Mr. C. A. Marshall, engineer of tests, and given in the discussion on Mr. P. G. Salom's paper before the American Institute of Mining Engineers, referred to on page 36. The conditions of tests are thus described:

Upon the point of time, I present tests of two heats of our steel, similar to that made for cruisers, with statement of speed and times from passing elastic limit to breaking. Specimens are alike throughout, being $\frac{1}{8}$ inches thick and planed to $\frac{1}{4}$ inches width.

TABLE XXVI.

Heat number.	Elastic limit per square inch.	Ultimate strength per square inch.	Elonga- tion in 8 inches.	Reduc- tion.	Time.	Total time of test.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>m. s.</i>	
5017.....	42,080	65,150	24.8	47.1	3 10	Say 7 minutes.
5017.....	41,930	65,550	25.6	47.1	3 10	Do.
5018.....	38,450	61,830	27.2	50.3	3 30	Say 7½ minutes.
5018.....	37,870	61,670	28.5	50.0	3 40	Do.
5017....	42,070	66,450	26.6	46.8	14 0	22 minutes.
5017....	42,400	66,530	26.2	49.3	13 0	23 minutes.
5018....	38,280	62,410	28.7	52.0	11 0	19½ minutes.
5018....	39,000	62,000	26.3	48.8	10 0	17½ minutes.

The speed of screw was throughout about $\frac{1}{8}$ inch per minute. In the first four tests the pulling was continuous after passing the elastic limit. The last four were tested in accordance with the requirements of the Naval Advisory Board. A strain of 30,000 pounds per square inch was left on for five minutes, elastic limit taken, and subsequent strain applied in increments at half-minute intervals.

The difference in tensile strengths in these tests may not be due altogether to the conditions of testing, but chiefly to difference of quality or physical condition. Thus, if we take the elastic limits as a measure of this condition, an artifice which we shall hereafter consider, and these values were obtained under identical circumstances in each case, and alter the figures for tensile strength proportionally so as to bring all the pieces of each heat to the same basis of elastic limit or assumed physical condition, we shall have the following averages without alteration in the values for elongation and reduction, which are apt to be affected by small differences of dimension as well as by the conditions of test:

TABLE XXVII.

Heat number.	Elastic limit taken as basis per square inch.	Corresponding ultimate strength per square inch.	Final elongation in 8 inches.	Reduction of area.	Time from elastic limit to rupture.	Total time of test.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>m. s.</i>	
5017	42, 235	65, 620	25. 20	47. 10	3 10	Say 7 minutes.
5018	38, 640	62, 525	27. 85	50. 15	3 35	Say 7½ minutes.
Average		64, 075	26. 52	48. 63	3 22	Say 7½ minutes.
5017	42, 235	66, 490	26. 4	48. 05	13 30	22½ minutes.
5018	38, 640	62, 205	27. 5	50. 40	10 30	18½ minutes.
Average	40, 438	64, 347	26. 95	49. 22	12 0	20½ minutes.

The average difference in tensile strength is now 270 pounds in favor of the increment testing, but while one heat gives a difference one way, the other reverses it. The real difference due to the manner of testing is probably inappreciable.

THE PHYSICAL AND CHEMICAL CONDITION OF THE TEST PIECE.

Another very prominent source of discrepancy in results from different pieces of material from the same heat is the difference in condition of the test pieces. These differences arise from four main causes, viz: (1) inequalities in the chemical composition of different parts of the same heat and especially of different parts of the same ingot; (2) inequalities in physical homogeneity in different parts of the ingot, arising from varying extent of liberation of occluded gases in cooling; (3) varying amount and nature of work of reduction from the ingot; (4) difference in heating and in the temperature of finishing, as well as all the conditions of cooling and subsequent treatment.

The first is due either to the irregular diffusion of manganese by being added to the charge too soon before tapping, a very rare occurrence now, or more generally to the phenomenon of hard centers or the segregation of the hardening elements to the center and top of the ingot during cooling. This latter condition is very generally prevalent to a greater or less extent, and sometimes very seriously so. It is promoted by very high temperature of cast and subsequent slow cooling, and is especially noticeable in Bessemer steel. It may easily affect the chemical results obtained from the same piece according to the depth of drilling and shape of point of drill, and give rise to very anomalous conclusions.

The second source of discrepancy alters the physical homogeneity from point to point as the first does the chemical quality, and somewhat in the same manner, the top of the ingot, especially when top cast, being much more honeycombed than the bottom, and, although more numerous near the sides of the ingot, the blow-holes are generally much larger and more injurious near the center.

The effect of work of reduction at a heat is generally to increase both tensile strength and ductility, the product of the two being considerably increased. If the material be originally much honeycombed as cast, both qualities are much increased and the contraction of area likewise. For this reason, a certain minimum amount of work of reduction is generally considered necessary in order to obtain practical homogeneity of structure, and for ship and boiler plate at least twenty reductions of thickness are deemed necessary in most of the large steel works in Great Britain. If the ingot be reduced in both width and thickness, or edged down, as in shapes or merchant steel and wire rod, less reduction is allowable, and it is then reckoned as reduction in area of cross-section.

The conditions of heating undoubtedly affect the physical structure, from the extreme of overheating to comparatively cold forging or rolling, but the subject is too complex for treatment here. At whatever temperature worked, the temperature at which the piece is finished and allowed to cool off, together with the conditions of cooling, very seriously affect the physical tests. Thus if a plate or flat cools, as is generally the case, in contact at various points with a cast-iron straightening plate, necessarily a good conductor, cooling is more rapid at the points of contact and over the surface towards the plate, and initial strains are set up sufficient to warp the piece and even cause failure when these strains are reversed in straightening or subsequent cold shaping, and this effect is greater the higher the temperature of finishing. Another curious case is that of a deck beam which leaves the rolls comparatively straight, but with bulb, web, and flange, all at different temperatures and therefore contracting unequally on cooling, as evidenced by the considerable camber of the cold beam from the greater contraction of the bulb, finished at the highest temperature. A very complex, though regular, condition of strain must be set up, especially near the fillets joining the web to bulb and flange.

From all these causes, widely differing results are easily obtained by the same experiments from material of the same heat, and it remains to be seen if there is no basis to which the condition of the piece may be reduced. We shall consider this point more fully in studying the curve of carbon properties of the Cambria steel; it will suffice now to state the principal points.

For difference of chemical composition there can be no measure other than actual analyses of the test piece. Laminations, arising from blow-holes or other cause, will generally appear in the fracture and particularly affect the contraction of area. The condition as to internal strain, or comparative annealing, arising from whatever cause, can probably be measured for any known quality of metal by the elastic ratio or the ratio which the principal elastic limit bears to the ultimate tensile strength. Thus if we have a large average of results for material of given chemical quality, any departure from the average as to physical condition, other than lack of homogeneity, will be fairly well indicated by difference of elastic ratio from its average value. This proposition will be fairly well established later on, and its importance will be readily appreciated.

STRAINING THE PIECE.

In placing the piece between the grips it is necessary that the line of resultant tensile resistance of the piece shall lie in the line of the resultant load producing stress, unless the cross-heads are held more rigidly than is usual, otherwise a cross-breaking is set up. The less ductile the material the more important it is that this condition may obtain. Thus if a filleted test piece of spring steel, taken from a bar of tapering thickness, be placed in an ordinary machine, centrally from edge to edge, its line of resultant tensile resistance may yet be so much out of center, on account of the unequal thicknesses at the two edges, that fracture will occur on the fillet where the sectional area is much larger than in the straight-sided portion. In such ductile material as mild steel for ships and boilers, the consequent effect would be very small or negligible, but in the less ductile materials it must be looked out for.

On the first application of stress the piece stretches in a more or less regular manner, the strain being proportional to the stress producing it. In short pieces of unannealed material this elastic extension as measured by electric contact instruments (see page 501) does not generally appear so regular as to produce a straight-line diagram, but lack of perfect straightness of test piece and the irregular hold of roughened grips under light load may produce apparent irregular extension or unequal distribution of stress, and consequent strain, in the cross-section, affecting the hold of the index arms. In fact, these considerations certainly prevent much reliance being placed upon individual results for modulus of elasticity obtained from short pieces, and would appear to make the average value too small. If, however, the modulus is desired, the piece must be straight—should have been perfectly straightened at the finishing heat at the rolls; cold straightening to any extent may affect the result. The stress for which the extension is to be noted must not be too near the principal elastic limit, generally about 10,000 pounds below its probable value, and the measuring apparatus, both for load and extension, must be both delicate and reliable. It is particularly necessary that the load should be uniformly maintained while the extension is measured, and there is consequent difficulty in obtaining consistent results on most of the hydraulic machines in use on account of leakage in the plunger packing or, more generally, in the pumps. Inasmuch as the elastic extensions are extremely small, a very valuable addition to such machines would be a valve of special design and workmanship, so as to be, and remain, perfectly tight, inserted between the cylinder and pumps, and an attachment to the main cylinder consisting of a small cylinder with screw piston, or otherwise designed, for producing small changes of volume or pressure. Such an attachment would also be of great value in determining the limit of elasticity.

After taking the readings for modulus of elasticity, a gradual increase of stress at length produces a slightly disproportionate extension, the corresponding value of the stress being taken as the limit of elasticity for such uses of the material as will permit of little or no permanent set in use, with comparatively high working loads, such as for ordnance and spring steels. For the mild steels used for structural purposes, we prefer to call this the *first* elastic limit, and it may be mentioned that its value may, to a certain extent, be affected by any lack of coincidence of the resultant lines of action of the load and of the tensile resistance. Further increase of stress causes a point to be reached where the extension

becomes entirely disproportionate, a very slight increase of stress producing an extension no longer requiring micrometric measurement to be appreciated. This point we will call the *principal* elastic limit, and for structural steels it is the only one which need be taken into account. From this point the strain diagram, as ordinarily constructed (see page 147, *et seq.*), accurately represents the behavior of the material at the elastic limit, frequently becoming nearly parallel to the axis of extensions. It is this feature which allows it to be easily obtained for the soft steels under continuous test, because in a screw, or a tight hydraulic, machine, the beam refuses to hold up the load, and, if the piece still retains a coating of mill-scale, which is usually the case in testing plates and shapes, the brittle scale commences to crack, generally near the fillets. In the ordinary test of plates, where the test pieces are removed by shearing, the effect of the bending on shearing and the subsequent cold straightening may be such as to largely remove this peculiarity of the diagram by originally straining the material beyond its elastic limit.

The cracking of the scale on a mild steel test piece at and beyond the elastic limit illustrates the homogeneity of the material, for it proceeds in cross-lines on the surface, making, as nearly as may be, an angle of 45° with the direction of tensile stress—the lines of maximum shearing stress in a homogeneous material—and therefore, parallel or at right angles to each other. The same thing may be even better seen on the surface of the side in tension of a bar under transverse test; on the compression side of such a bar the scaling takes place at right angles to the stress.

After a certain amount of stretching at the elastic limit, depending both on the chemical quality of the steel and its previous treatment (possibly also on the method of manufacture in the furnace), the relation between the stress and strain is shown by a line generally regular, concave to the axis of extensions, and of diminishing curvature, until, near the maximum load, the curve becomes very flat, rendering the extension at the highest point difficult to measure with accuracy. When this highest point is just reached the piece is said to be at the “point of failure,” or at “tensile limit.” The corresponding value of the ordinate of the strain diagram is the “ultimate tensile strength,” always the chief feature, and sometimes the only one, determined by the tensile test. This value is sometimes erroneously called the “breaking strain,” but “breaking” would better apply to the load at fracture, and “strain,” in scientific language, denotes the effect of the stress and not the stress itself.

Some experimenters, notably Sir William Fairbairn, have gone so far as to consider the condition of the piece at “tensile limit” as final, at least for structural purposes, and confine their record to ultimate strength and extension at tensile limit. It has been urged that it denotes the extreme values to which the material can ever be strained, for any appreciable time, without rupture, and that the rivets would become seriously started in boilers and the skin-plating of ships causing excessive leakage. The difficulty of measuring the corresponding elongation with the necessary accuracy has as yet prevented requirements being based on the condition at tensile limit. Both at the Norway and Cambria Iron Works, the elongation at tensile limit was measured, giving values fairly uniformly below the final elongation (see Table IX. and p. 455). The condition of the material at this point of failure is peculiar. The piece commences to heat up at the point where necking subsequently occurs slightly before the maximum load is actually reached.

Also, after commencing to neck at one place, the piece sometimes gains strength there sufficiently to neck and actually break in another place, as many as three such neckings having been observed in well-shaped 8-inch pieces.

On passing the point of failure, the scale-beam drops and the gauge load to the point of fracture continuously diminishes, the piece drawing out or necking, generally over a short length, and fracture taking place on a considerably reduced area in the mild steels. The metal is in a more or less plastic state, flowing like lead under pressure—not like it under a constant stress, but with increasing resistance from unit of area. The amount of this increase of resistance, and an idea of its rate, may be obtained from Table XXXII. of tests made on the Rodman machine at the Washington Naval Arsenal, for comparison with the results of the same material on other testing machines. The average value of the resistance per square inch actual at tensile limit, for the representative pieces, is about 78,000 pounds, while at rupture it has risen to something over 110,000 pounds.

THE ELASTIC LIMIT.

No term expressive of physical quality of material has so confused a meaning as elastic limit. Its original definition is that stress which, slowly applied and removed, will produce no permanent distortion. The value obtained under this definition in actual testing is uncertain, depending on the delicacy of the apparatus employed and whether or not the piece was originally perfectly straight and its section has been uniformly strained, and requires great care on the part of the experimenter. The same objections apply to the definition adopted by Wertheim and several other physicists as the stress which produces a permanent elongation of .00005 of the original length. In certain experiments on cold-rolled iron and steel, Thurston has adopted a different *permissible* permanent set.* Such definitions are essentially arbitrary.

The elastic limit is also sometimes understood to mean the stress which, although not causing fracture at once, will do so if repeated a sufficient number of times. Plainly, to obtain results under this definition is impossible in any system of commercial tests. Spangenberg, reasoning from his own and Wöhler's experiments, concludes that the working strength of wrought iron is less than its elastic limit as determined by first appreciable permanent set.

Styffe propounds a much more satisfactory definition thus:† “If an iron or steel bar be gradually extended by successive loads, which at first are so small that they occasion no perceptible permanent elongation, but are gradually increased, and are always allowed to operate for as many minutes as each additional weight is per cent. of the entire load, then the author regards as the ‘limit of elasticity’ that load by which, when it has been operating by successive small increments, as above described, there is produced an increase in the permanent elongation which bears a ratio to the length of the bar equal to .01 (or approximates most nearly to .01) of the ratio which the increment of weight bears to the total load.” Although complicated in expression, the value so obtained is believed to be truly indicative of a definite quality of the material. To obtain it in practice, the curve of permanent set is

* On the Strength, &c., of Cold-Rolled Iron and Steel. Pamphlet, 8 vo., Pittsburg 1878.

† Iron and Steel, by K. Styffe, translated by C. P. Sandberg, p. 30.

drawn and the value corresponds to a certain inclination of its tangent and almost invariably occurs at a point of great change in its direction. It is interesting to note that, at the limit so obtained, "the permanent elongations begin to be so great that they become of practical importance;* and in bars which have not been freed from the scale formed during annealing, the limit may be observed by the scale beginning to peel off." It will be remembered that this differential action of the scale cracking was successfully made use of in determining the elastic limit at the Cambria Iron Works.

From two of the above definitions based, one upon first appreciable permanent set and the other on a distinct peculiarity in the curve of permanent set, are derived two definitions applicable to the conditions of continuous testing and in very general use. The first of these, advanced and used by Kirkaldy, may be defined as the stress beyond which equal increments of stress cease to produce uniform increments of stretch. It is evidently based upon the conception that the elastic curve is a straight line, or the strain directly proportional to the stress, so that any departure from a uniform rate of extension under uniformly increasing stress must be caused by the production of permanent set. This assumption is by no means strictly correct even theoretically, since recent determinations show that the elastic curve, although comparatively straight, is seldom perfectly so, its exact nature being somewhat capricious, involving uncertain conditions of physical structure and initial strains. Further, the point so determined is not generally indicative of a sufficiently definite quality of material, and appears to be particularly affected by certain kinds of mechanical treatment not materially affecting the other properties of the metal.

The second derived definition applicable to continuous testing is that stress at which the increase of extension becomes altogether disproportionate to the increase of stress. The corresponding feature of the strain diagram for ordinary wrought iron and steel is very marked, occurring as either a sudden change of direction without contra-flexure, as in Fig. *a*, or with contra-flexure, as in Fig. *b*.

It is interesting to state that of these, Thurston† considers the second indicative of lack of homogeneity across the direction of rolling, the blow-holes of the casting drawing out into long microscopic or less than microscopic capillary openings. The deduction is made by analogy from the diagrams produced by fibrous woods, such as locust and hickory. While very suggestive, it can scarcely be considered as established.

Where this peculiarity is marked, it is evident that the elastic limit so determined must agree very closely with that obtained from Styffe's definition, and is equally representative of a definite quality of the material.

Comparatively cold finishing or cold straightening, and any lack of uniformity of the metal or in the trans-



Fig. a.

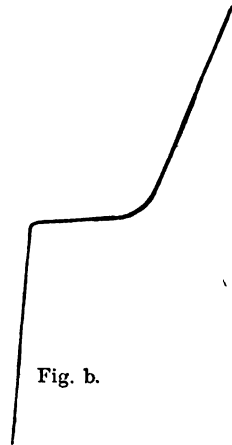


Fig. b.

* Presumably for metal to be used for structural purposes.

† Materials of Engineering, Part II, p. 531.

mission of stress to it, will affect the sharpness and extent of the irregularity. Graphitic carbon and high phosphorus would also appear to influence it.

It is evident that the altogether disproportionate extension at this point must cause adhering mill-scale of very low ductility to crack off; and, as previously remarked, in cracking it follows the lines of maximum distortion. The indication is of great value in commercial testing when the scale has not been removed in shaping the test piece, and indeed constitutes something of an argument in favor of using test pieces as nearly as possible in condition as finished at the rolls. A more generally observed indication depending on the same peculiarity of the strain diagram is the fact that, if the ram or screw of the testing-machine moves slowly and uniformly while the beam is kept balanced, at this point the beam will suddenly drop and will not lift again until the piece has been extended beyond the irregularity and increase of stress and of strain resume a normal proportion. For ordinary structural wrought iron and steel these two indications of the beam dropping and the scale cracking are generally sufficient to determine the elastic limit under this definition with great accuracy. The elastic limit determined from one or other or both of these indications, and which we will call the *principal elastic limit*, is that generally used for structural material in this country. In Great Britain, Kirkaldy's method is very generally adopted.

We have the means of comparing results for the same material under the three definitions most in use. Thus the Norway steel pieces in Tables XXXI. and XXXII. gave an average for two pieces of 33,707 pounds per square inch, or 53.5 per cent. of the ultimate strength, by the method of first appreciable permanent set at the Washington Naval Arsenal; 32,325 pounds per square inch, or 51.44 per cent. of the ultimate strength by the peculiarity of the strain diagram; and the inspector making the tests at the works and using Kirkaldy's method reports 26,190 pounds per square inch, or 41.67 per cent. of the ultimate strength. The need for the general adoption of some one or other definition is evident from these differences.

The difference between determinations under the first two of these definitions—first permanent set and peculiarity in the strain diagram—is not always in the same direction as above. In Table XXXI., the elastic limit for the pieces tested at the mills is as given by strain diagram; for those tested at Washington, the method of first permanent set was used. The Chester steel gives practically the same absolute value, but a greater ratio, by permanent set; the Norway steel is as above, both value and ratio greater by permanent set; one piece of Black Diamond steel showed abnormal results by permanent set, the other gave less value and ratio by permanent set; the Cambria steel gives much less value and ratio by permanent set, the average differences being 3,870 pounds per square inch and 5.18 per cent.

Adopting the principal elastic limit as that indicative of the proper quality for structural steel, examination of the above tables referred to shows that if a requirement for elastic limit were to be exacted, unless it were placed much lower than generally reckoned, the manufacture of some of the steels delivered would have to be radically changed. Thus, for the bridge steel (App., p. 577), the elastic ratio demanded for 80,000-pound compression metal is 62.5 per cent., and for 70,000-pound tension-metal 57.14 per cent., and it is very generally reckoned that ship-steel should give an elastic ratio of from 55 to 70 per cent., averaging somewhat above 60 per cent.

Engineers are now very generally of opinion that permissible working loads should be determined with reference to the elastic limit, having regard to fluctuation of stress and the general duty required of the piece. Other qualities being equal, material of relatively high elastic limit would therefore be desirable.

On the other hand, this can be carried too far. Steel can be made with high elastic ratio by carrying too high phosphorus and keeping the other hardening elements and impurities as low as possible; but such metal, though it may give very fair results by ordinary tensile tests, is said to be lacking in "body," will not stand much working or many heats, and is more liable to snap under sudden application, or fluctuation, of stress.

Relatively high elastic ratio for metal suitable for ship-building, when finished, cooled, and subsequently treated in a normal fashion, is to be obtained generally in two ways, by carrying comparatively high phosphorus with low silicon and by great amount of reduction or mechanical work from the ingot. Opinions may differ on the first point for reasons above stated; but for ship metal made by the open-hearth process, with silicon not above .04 per cent., it would appear that the phosphorus may be carried with advantage to very near the Bessemer limit of .1 per cent.

Considerations of safety in working are generally those borne in mind as controlling the amount of mechanical work necessary, but indirectly the elastic ratio is undoubtedly affected. The comparatively high ratio reckoned on for mild steel in Great Britain is largely due to the method of manufacture, the reductions of thickness from the ingot rarely falling below 20, and much of it generally under the hammer. Kirkaldy,* experimenting on the open-hearth steel plate of the Steel Company of Scotland for the Board of Trade, obtains the following results of 48 tests under his definition:

Thickness of plate.	Mean elastic stress per square inch.		Mean ultimate stress per square inch.		Mean elastic ratio.	
	Length- wise.	Cross- wise.	Length- wise.	Cross- wise.	Length- wise.	Cross- wise.
$\frac{1}{4}$ inch	<i>Pounds.</i> 42,560	<i>Pounds.</i> 42,780	<i>Pounds.</i> 69,430	<i>Pounds.</i> 70,330	<i>Per cent.</i> 61	<i>Per cent.</i> 60
$\frac{3}{8}$ inch	35,390	35,170	64,730	64,060	54	55
$\frac{1}{2}$ inch	35,390	34,940	66,080	65,180	53	53
1 inch	33,375	33,150	62,720	62,720	53	52
Total mean...	36,510	36,510	65,630	65,410	55	55

It is seen that a difference of 8 per cent. of elastic ratio, or nearly 15 per cent. of its mean value, exists between the 1-inch and the $\frac{1}{4}$ -inch plate, and that the ratio rises continuously as the thickness diminishes and very rapidly below $\frac{1}{2}$ -inch thickness, owing, doubtless, to lower temperature of finishing and more rapid cooling. It is probable that the mean value of 55 per cent. under this definition would correspond to not less than from 60 to 62 under the definition commonly used in this country for structural material, and the difference is apt to be greater when the metal has been worked under the hammer.

The results of the Cambria steel well illustrate the general conclusions. Being made into shapes, the work of reduction was very great; little of it failed in the working, and none without evident cause; its average results on tensile test are perhaps rather better than those of the other

* Merchant Shipping Experiments on Steel, Parliamentary Paper, C. 2897, London, 1881.

steels; it was undoubtedly made cheaper; less was rejected on test; yet its phosphorus will probably average .085 per cent., and its average elastic ratio was about 64.5 per cent. Similar information is not available for the other steels, but 10 heats of Norway steel gave an elastic ratio of 53.74 per cent., while the average phosphorus is believed to be below .055. Recent heats of Chester steel are much higher in phosphorus than most of the steel delivered from these works, ranging from .057 to .1 per cent., as we think with advantage for the purpose to be served.

For boiler metal or ship-steel to stand flanging or hot working, the phosphorus should not generally exceed .06, the lower the better, and under ordinary methods of manufacture comparatively high phosphorus is not at all admissible for such material. On the other hand, a great increase in the work of reduction is highly advisable and may even be necessary for the thick plates used in marine boilers.

MODULUS OF ELASTICITY.

Within the elastic limit, the relation of stress and strain, is approximately that of direct proportion, being expressed by the simple equation $p = Ee$, p being the stress, e the corresponding change of unit length in the line of force producing stress, and E a factor commonly called the modulus of elasticity, and evidently constituting a measure of stiffness or resistance to distortion. If $e=1$, $p=E$, or if it were possible without passing the limit of elasticity to double the original dimension under tension, the quantity E would be the stress necessary. For such materials as mild steel the measure of the stiffness is very great, and, under ordinary stresses, the corresponding extension is very small. The shorter the length strained, the more difficult is the exact measurement of the extension, so that in any system of commercial testing it is very difficult to obtain correct values of the modulus with the short pieces necessarily employed. In such cases, errors themselves very small may produce serious discrepancies in the results, and to avoid them much greater nicety in the construction and manipulation of instruments is required than can usually be obtained at steel works. Accordingly such determinations are generally reserved for the careful and exact tests of scientific experimenters.

Of late, however, attention is being directed extensively to the qualities of materials under stresses approximating to the working loads, which themselves are now based more frequently from consideration of elastic limit than, as formerly, of ultimate strength. In trussed structures, as roofs, and more especially bridges, the considerations governing the transmission of static stress from member to member, the strength of long columns or compression members, the development and transmission of internal oscillations, and the desirability of reducing deflection in many cases, would appear to be attracting attention especially to stiffness and elastic limit, so that requirements for the latter are very generally exacted, and for modulus of elasticity have been demanded (see Appendix p.211.) In the determination of this very important quality, if only a satisfactory apparatus can be devised, the immense amount of material tested for commercial purposes affords means of investigating extreme values and the law of variation with reference to general quality and method of manufacture, such as cannot be obtained with the limited testing of specialists. Immediate point is given to this investigation at the present time by the facts that the wear of steel rails appears to be influenced by the intrinsic stiffness of the material, and the strength of long columns is very considerably dependent

on this quality. The solution of the question as to the most suitable material for these purposes is evidently of the greatest importance.

Whatever apparatus be employed, the total error of determination will be influenced by the straightness of the piece, its lack of homogeneity or the unequal transmission of stress from the grips to all parts of the section, the absolute length of the measured part, the stress selected for the observation of extension, and variations of temperature. The apparatus should be easily applied and removed, should read to the necessary degree of fineness, and its accuracy should not be influenced by the amount of stress to which the piece is subjected; it should take account of lack of homogeneity or unequal transmission of stress, and not be seriously influenced by changes of temperature in recording its indications. Finally, it should not be too costly or liable to get out of order.

Numerous devices have been employed in this country, in general either depending on delicacy of touch or of sight with the means of producing small motions, or on the enlargement, by levers or other means, of the small extensions to be measured. Having pointed out the needs of the case, it is unnecessary to describe them, as all are deficient in one or more points, and we will confine ourselves to the instrument used during this inspection at the Cambria Iron Works, and which has been more generally used than any other, the Olsen electric-contact micrometer.

The micrometer consists of two frames, one to be secured to the upper part of the piece and the other to the lower, the length between the holding screws being that adopted for test. The upper frame consists of a brass arm, A, with removable clamp piece B, both made with right-angle bends at the center, being originally intended for squares and rounds. When flats are tested, the angle on the arm is filled by the insertion of a piece, as shown by the broken line. The frame is secured to the piece by the screw C, set up tight against the piece, the reaction holding the clamp B against the milled-head screws D, which are adjustable to suit the thickness of the piece tested. Contact is therefore by the set-screw point on one side and considerable pressing area on the other. From the ends of the arm extend $\frac{3}{4}$ -inch brass rods, carried by insulated gutta-percha sleeves e, and projecting above sufficiently for the insertion of wires to the battery. The lower part is similarly secured to the piece, but the arm is differently shaped, as shown, with broad split ends, in which work $\frac{3}{4}$ -inch screws of the very best manufacture, 50 threads to the inch, with micrometer heads 2 inches in diameter, divided on the circumference into 200 equal parts. The micrometer circle is read in connection with the fixed scale, divided into fiftieths of an inch—the pitch of the screw. Reading to the nearest division of the micrometer head, therefore, the 0.0001-inch can be recorded, and the eye can determine the next place of decimals fairly accurately. An electric wire leads from the lower frame to an alarm bell in circuit with a battery and the rods of the upper frame. The apparatus being attached to the piece centrally and so that the set screws are the proper distance apart—determined by a shorter rod or scale of suitable length being just capable of insertion without pressure between the surfaces of the clamp pieces—the screws are turned in succession until the point just touches the end of the insulated rod, contact being noted by the ring of the bell, the corresponding readings are noted, and the screws run down to avoid any pressure or contact due to tilting of the arms as the piece is strained. The proper stress is then applied,

new readings taken, and the mean taken of the extensions noted by the two screws.*

The trouble with this apparatus is the uncertain effect of the friction of the surfaces of frame and piece in contact as the one surface elongates and the pressure between them diminishes. There is reason to believe that on the average this results in too great a value of the extension, especially in filleted pieces, and a correspondingly low value for the modulus, the average defect in the steel tested at Johnstown being reckoned at about 300,000, or more. The lowest modulus recorded was 24,360,000, but as no special precautions were taken to have the pieces perfectly straight, or any estimate made as to the effect of observed curvature, this is not to be taken as reliable, the real minimum probably being considerably above this. The highest value for a heat was 31,475,000 (heat 4950, mean of two pieces), and the mean value for 42 heats 27,720,000. From the observed defect of the micrometer and general lack of perfect straightness of the pieces it is believed that this value is too small by about 600,000, and it is probable that the value for this steel varied from 26,000,000 to 31,500,000—rarely approaching the latter—with an average of 28,250,000.

As affected by the conditions of finishing and subsequent treatment, it appears that this steel cold-rolled has a modulus about 500,000 less, and annealed about 1,000,000 more, than in the average condition of finishing at the rolls.

As affected by change of carbon, the curve of carbon properties (Plate XXVI.) shows a slight rise, with increase of carbon, over the range of tests. As the modulus closely follows the density of material of given nature, it is believed that it may reach a maximum value for this steel at from .30 to .35 per cent. of carbon, but must diminish with further increase.

The modulus of elasticity of mild steel in compression is generally taken the same as for tension. This was very closely true in some tests of shaft steel recently made on the Emery machine at the Watertown Arsenal for this Board.

Mr. James Christie, from some recent experiments on Bessemer steel of structural quality,† gives the value of the modulus under compression much less than under tension. Thus for .12 carbon steel he obtained for E in tension 27,030,000 to 32,780,000, with an average value of 30,135,000; while for compression the values were 15,132,000 to 24,490,000, with an average of 20,478,000. This result is anomalous, and should be very carefully verified before being accepted.

THE EXTENSION OF THE PIECE.

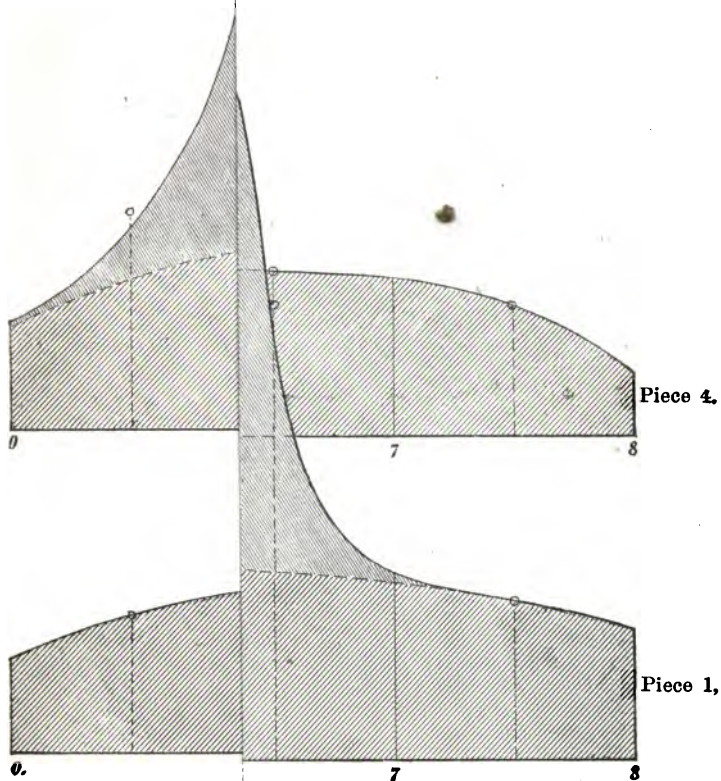
The total extension of the piece is made up of three elements, the elastic extension, always a very small quantity; the extension under increasing load up to tensile limit, generally considered as fairly uniform over the length, and constituting the most important part of the total extension; and the extension on flow or necking.

An idea of the disposition of the total extension along the length, together with the relative amounts of the two chief elements, may be obtained from Plates X., XI., and XII., extension diagrams for two pieces each of three heats of Cambria steel. Although selected at random, both the quality of the heats and the behavior of individual pieces are

* Before affixing the micrometer to the piece a stress of about 8,000 pounds to the square inch was very generally applied and removed, in order to tighten the grips and remove initial strains, which sometimes seriously affect the very first extension under low stress.

† Trans. Am. Soc. Civil Engrs., Vol. XIII.

Scale 5"=1" Extension.



Heat.	Marks.	Fracture.		Appearance and Nature of Fracture.
		Lbs. sq. in. of fractured Area.	Time of Test. Mins.	
5565	1	5,750	15½	Silky-irregular
"	4	4,860	12½	"-irreg'r-cup

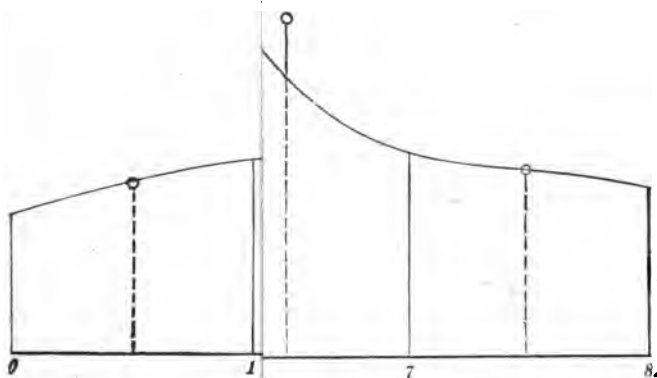
MOSS ENG. CO., N. Y.

Face page 136.

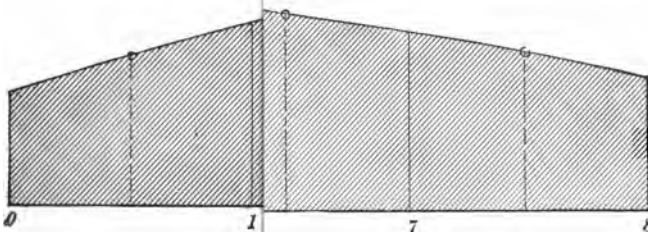


E

Scale 5"=1" Extension.



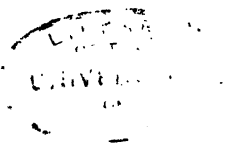
Piece 2,



Piece 3.

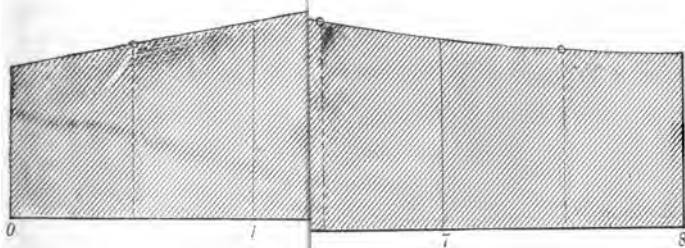
Heat.	Marks.	Obs. sq. in. of fractured Peren.	Time of Test. Mins.	Appearance and Nature of Fracture.
5567	2	2,530	14	Silky-plane.
"	3	"	14½	" "

MOSS ENG. CO., N. Y.

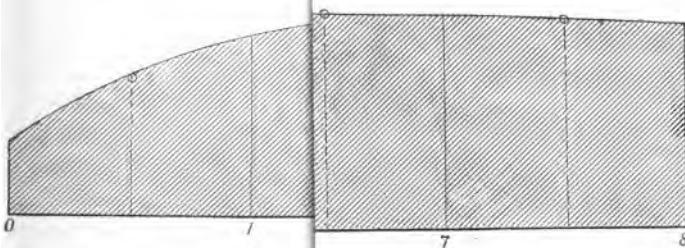


E

Scale 5"=1" Extension.

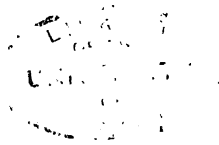


Piece 2.



Piece 3.

Heat.	marks.	carbon.	ure.	me	Test.	Appearance and
-------	--------	---------	------	----	-------	----------------



fairly representative. Heat 5565 is comparatively hard, having a strength of 67,000 pounds; 5567 is softer, having a strength of 65,800 pounds; while 5569 is near the limit of ship metal, having a strength of 60,600 pounds. The fractures of 5565 are near the end, the others near the middle, except that of 5567-2 which very well illustrates a hard spot. The diagrams are obtained by measuring the extension of each inch and setting up the corresponding value as ordinate in the middle of its inch. The highest point is at the fracture, and is obtained by subtracting unity from the reciprocal of the fraction for final area. Then the mean ordinate of the curve over each inch must be the measured extension for that inch, and by trial and error, with the aid of a planimeter, a curve may be obtained fulfilling this condition. The two essential elements of extension are then represented by a curve on the whole length as base—and which may be called the “body” curve—topped by the peaked or wave-like curve of flow, and the first curve is sufficiently defined to allow the line of separation to be distinctly drawn. It is not, however, correct to consider the area of the first as the extension at tensile limit, as might naturally be supposed. A comparison of the diagrams with the tables shows that it is very probable that flow commences somewhat before tensile limit is reached. Thus the area of the body curve of piece 5565-1 is 18.24 per cent., while the extension at tensile limit as measured is exactly 20 per cent. Similarly for 5565-4, the figures are 17.2 per cent. and 19.25 per cent., respectively, the mean difference for the heat being 1.9 per cent., which represents the amount of stretch due to flow before the elongation at tensile limit was measured. For piece 5569-3 the difference is only .83 per cent. It will be noticed that for these three pieces the body curve is practically flat-topped.

Pieces 5567-3 and 5569-2 illustrate an essentially different behavior. The body curves have considerable spring, and their areas are in excess of the measured extensions at tensile limit by .6 and 2.43 per cent., respectively, showing that the flow has not been confined to a short length only, but is made up itself of two elements, the one extending over the greater part of the length of the piece and the other the ordinary local necking.

The length of the piece affected by the local flow is pretty constant for the first-mentioned pieces, being 3 to $3\frac{1}{4}$ inches for pieces 5565-4 and 5569-3, and $2\frac{3}{4}$ inches for piece 5565-1. In the pieces developing the double flow the length affected by the strictly local flow is less, being 2 to $2\frac{1}{4}$ for piece 5567-3, and only $1\frac{1}{2}$ for piece 5569-2.

The absolute value as well as the proportion of the extension due to local flow is variable, as shown by the figures, being less in the pieces developing double flow; from 6.3 per cent. in 8 inches, or 26.81 per cent. of the total, for piece 5566-4, to 3.74 per cent. in 8 inches, or 13 per cent. of the total, for piece 5569-2.

Piece 5567-2* illustrates the effect of a hard spot near the center of the piece. The extension and reduction of area have been interfered with; but the area of the flow curve is greater than in the other cases, although the line of separation cannot be exactly defined. The effect on the flow and the reduction of area is indeed very much as if the length of the test piece had been 4 inches instead of 8, the hard spot acting as a fillet or other increase of area.

Attention is called to the effect of the fillets at the ends, although the pieces were at least $8\frac{1}{2}$ inches between fillets. Especially noticeable is piece 5569-3, in which one witness mark was accidentally put slightly

*This piece measured very uniformly along the length, so that the effect is not due to excess of resisting area over any short length, but to lack of homogeneity.

up on the fillet. It is perfectly evident that the effect of the fillet must be always to slightly diminish the ductility if the piece is exactly 8 inches long between fillets.

As has been remarked, the condition of the piece at tensile limit is considered final by some experimenters, and it has been proposed to base specifications accordingly.

For the representative steels in Table XXXII. the value of the extension after tensile limit is 4.54 per cent. in 8 inches, or 19.98 per cent. of the whole extension, for the Norway steel; 5.64 per cent. in 8 inches, or 21.63 per cent. of the whole extension, for the Cambria steel flat; 5.07 per cent. in 8 inches, or 22.94 per cent. of the whole extension, for the Black Diamond steel; 6.66 per cent. in 8 inches, or 26.28 per cent. of the whole extension, for the Chester steel; and 9.64 per cent. in 8 inches, or 31.43 per cent. of the whole extension, for the Cambria steel deck beam; the average value being 6.31 per cent. in 8 inches, or 24.45 per cent. of the whole extension; or, roughly, one-fifth to one-quarter of the total extension of an 8-inch piece occurs after tensile limit. The extension before tensile limit is much more uniform, being 18.18 per cent. for the Norway steel; 17.03 for the Black Diamond steel; * 18.68 per cent. for the Chester steel; 20.38 per cent. for the Cambria flat, and 21.03 per cent. for the Cambria deck beam.

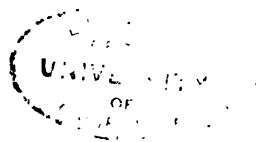
The average value of the extension at tensile limit for 23 accepted heats of Cambria steel given in Table IX. is 20.18 per cent. in 8 inches, the corresponding average total extension being 25.3 per cent., whence the average value of the extension beyond tensile limit is 5.12 per cent. in 8 inches, or 20.24 per cent. of the total extension.

Very similar results were obtained with the somewhat softer Norway steel, the average value of the extension at tensile limit for 30 heats given by Lieutenant Drake in his special report on proposed modifications of tests (p. 455) being 20.65 per cent. in 8 inches, with a corresponding average total extension of 26.81 per cent., whence the average value of the extension during necking is 6.16 per cent. in 8 inches, or 22.98 per cent. of the total extension.

FRACTURE.

Rupture of the piece is accompanied by a sharp report, except when, from some lack of homogeneity, it occurs by a tear from one point with a dull thud. This suddenness prevents the action from being closely examined, but its nature is easily seen in breaking pieces punched or drilled in the center, which part more slowly. Rupture is then seen to occur by a sliding action, or shearing on a quasi plane, or combination of planes, making a pretty definite angle with the direction of the straining force. Of course we speak of the mild steels as giving way in this fashion. The lack of homogeneity in puddled iron, due to the interposition of layers of slag, generally prevents this action from extending continuously across the piece, and breaks it up into such a large number of discontinuous and irregularly disposed facets of fracture, that the governing law is not apparent. Nevertheless specimens of pure well-worked irons exhibit the tendency distinctly. The harder steels and iron do not rupture in this way, but with a square crystalline fracture. The appearance of the fracture of the soft steels is largely due to the exact conditions of rupture. Thus, if the action be one of pure shearing, the fracture shows fine and silky, just as the hardest steels

* It is 18.76 per cent. for one piece of this steel, and the behavior of the other piece was somewhat abnormal.



SHOWING FLOW OF METAL
IN TENSILE TEST PIECES OF CHESTER STEEL.

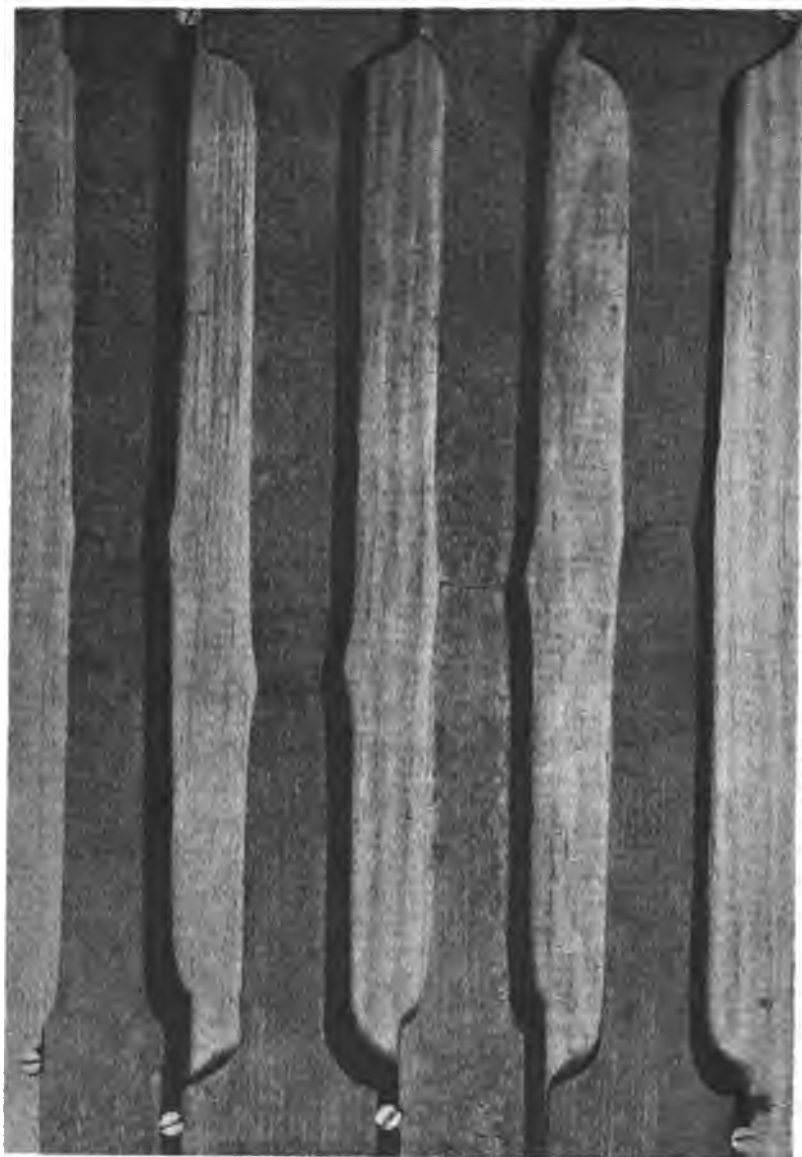


FIG. 1. TENSILE TEST PIECES.

show when sheared, and the same steel if necked and broken across suddenly will show a crystalline fracture of course. A crystalline fracture shows an essentially different action in breaking, and whether due to intrinsically different physical structure or to the conditions of fracture, it probably indicates the existence of variable resistance round any point in the metal.

The fracture of mild steel of good quality under tensile test is on a plane or planes making a more or less constant angle with the direction of the straining force. In rounds, as in rivet-bar, the cone of shearing is generally very perfect for some distance in from the edges, when it is topped by a collection of smaller facets lying across the section. An analogous section in flat bars is what is called a "cup" fracture, of equally inclined opposite planes from each wide side toward the central plane, with generally side or closing facets from the short sides of the section, like a ridge roof with end slopes. In flats the fracture is also frequently a continuous surface, nearly plane, across the thickness. Of the two kinds of fracture, the plane and the cup, the former probably denotes the greater homogeneity across the thickness of the metal. The larger number of fractures are distinctly one of these or a combination of the two. On the angles of fracture and the stresses producing rupture we shall have more to say later.

The thickness of the fracture in flat pieces is not uniform across the width, there being a considerable hollow towards the center of the fracture in the locally stretched part, the thickness being frequently 10 per cent. less than at the edges in the fractured area of pieces originally $1\frac{1}{2}$ inches by $\frac{7}{8}$ inch. The narrow side is also hollowed, but not appreciably.

The nature of the flow of the metal near the fracture is well illustrated in the opposite photographs of several samples of Chester steel by the position and arrangement of the originally equidistant scribe lines. It will be observed that the bowed cross-lines still cut the long lines at right-angles, and, since the density of the metal is found to be practically unaltered, the action is precisely similar to the flow of water in a smooth pipe of the form of the broken test piece.

MEASUREMENT OF FINAL ELONGATION.

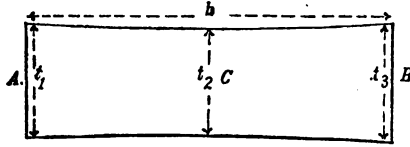
In making this measurement and that of final area, the use of forms to hold the two parts together when fitted saves time and promotes accuracy. The use of a direct vernier, such as described, p. 168, is also advisable as eliminating probability of error in subsequent division in rapid work. Care should be taken in removing the pieces from the machine to keep the fractured surfaces from striking anything, so that they will fit well. If the piece has torn from one point, the two parts will not be in a straight line when fitted as well as possible; in such a case they should be placed straight so as to touch at one edge, elongation measured, and the opening at the other measured and subtracted from the elongation before obtained.

MEASUREMENT OF FINAL AREA.

Some confusion has perhaps been caused by the use, in the records of tests, of the final area in per cent. of original area instead of reduction of area as commonly used in this country. The former is the more scientific function, has always to be obtained in order to get the latter, and amounts only to the substitution of a negative instead of a positive

scale of quality. The French call this quality the "striction" of the piece, and we have—

$$\begin{aligned}\text{Striction} &= \text{final area in per cent. of original area,} \\ &= 100 - \text{reduction of area in per cent.}\end{aligned}$$



To measure the final area, the pieces should be fitted, the least width measured, and the thickness at each edge, and in the center in the plane of least width. On account of the hollow in the section it is necessary to introduce a formula for the mean thickness. This is best done by applying Simpson's rule for three ordinates. Thus, if t_1 t_2 t_3 be the thickness at A, C, and B, respectively, and b the least width, we shall have—

$$\text{Final area} = \frac{b}{6} (t_1 + 4t_2 + t_3)$$

The slight calculation necessary arranges itself easily in the note-book thus, taking piece 4908-2, Plate VI., as example:

t_1		= .300
$t_2 = .272$	$4t_2 =$	1.088
t_3		= .308
		<hr/>
		6)1.696
		<hr/>
Mean thickness		= .283
Fractured width		= .936
Fractured area		= .2646

On account of the curvature of the section, it will very much increase the accuracy of measurement if screw gap gauges with round bearing surfaces are used.

As at present obtained, the fractured area is a very indefinite quality, few experimenters obtaining it in the same way.

At the Chester Rolling Mills, measurement for mean thickness was made half way from the center to one side on one-half of the piece.

At the Black Diamond Works, the mean of the thicknesses in the middle and at one side was taken. These both presuppose that the two edges will measure the same, which they will not generally do, but supposing $t_1 = t_3$, the error in mean thickness by the latter method is $t_1 - t_2$, or 1-6th the hollow of section.

6

At the Cambria Iron Works, the mean of the three thicknesses was taken as the mean thickness, the error being $\frac{t_1 - 2t_2 + t_3}{6}$, or one-third the mean hollow of the section.

At none could the pieces be measured as fitted together, one part only being measured, thus giving additionally high results for final area.

UNIVERSITY OF
MICHIGAN

TABLE XXVIII.

CAMBRIA STEEL.	Original Section.			Fractured Section.		
	Average Original Width.	Average Original Thickness.	Ratio Width Thickness.	Final Width in per ct. of Original Width.	Final Thickness in per ct. of Original Thickness.	Ratio Final Thickness Final Width per ct.
Tests of Finished Material . .	Inch. 1.250	Inch. .3724	3.357	Per ct. 73.14	Per ct. 66.97	Per ct. 91.57
Tests by Heats (113 heats) . . .	1.248	.4539	2.750	75.04	69.88	93.14
Certain Selected Tests(6 heats)	1.254	.6293	1.993	77.79	74.33	95.55
Four Special Tests(Table XXXI)	1.001	.4722	2.120	69.09	63.20	91.48

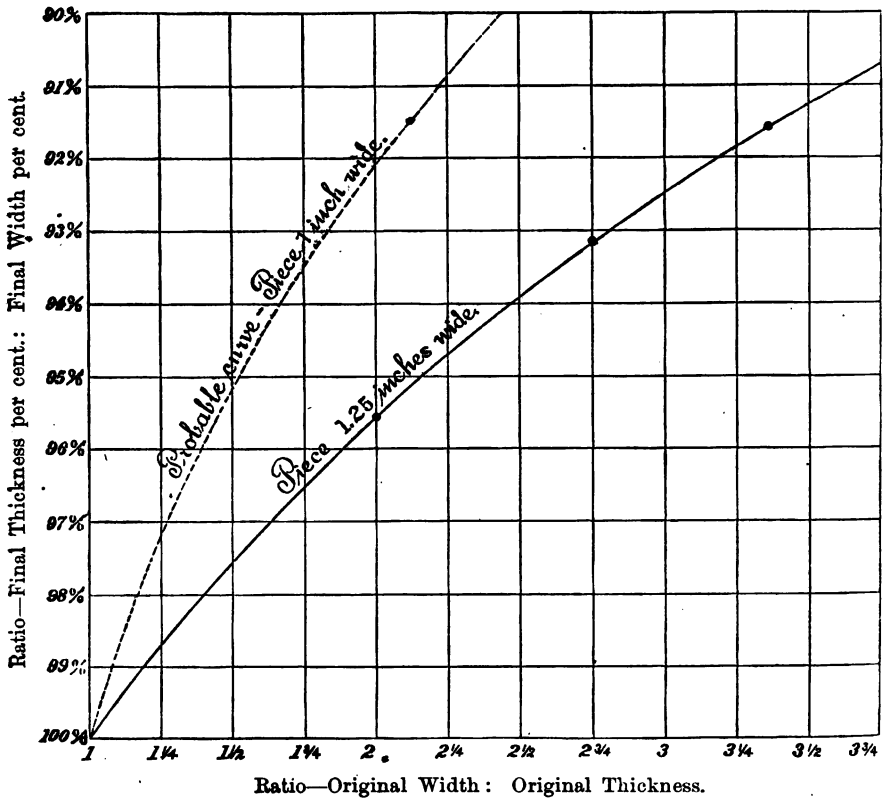


FIG. 17.

Diagram illustrating relative reduction of width and of thickness for 8-inch flat piece.

Identical and more correct methods will be used by all inspectors for any future work under the Board.

PROPORTIONATE REDUCTION OF WIDTH AND OF THICKNESS IN THE SECTION.

The reduction of area of a flat piece of rectangular section of greater width than thickness is not made up of equal reductions of width and of thickness, the reduction of the latter being invariably the greater. The proportion, with a given length of test piece, appears to depend upon the absolute size of the section and the ratio of its two dimensions. It may also be somewhat affected by the nature of the work of reduction in rolling. Table XXVIII. gives the results of numerous tests of Cambria steel in pieces $1\frac{1}{4}$ inches wide, of varying thicknesses, the ratio of width to thickness varying from 3.36 to 2,* and the diagram of Fig. 17 illustrates graphically the relation between the percentages of final width and final thicknesses. The curve terminates, of course, for a ratio of width to thickness of unity, or 100 per cent. The actual curve through the four spots, by accident or otherwise, is a circle, and construction on a smaller scale shows its highest point to be 85.75 per cent. for a ratio of width to thickness of $8\frac{1}{4}$ to 1, or for a thickness of .15 inch in a piece $1\frac{1}{4}$ inches wide. The four special tests of Cambria steel in Table XXXII., for pieces 1.001 inches wide, sectional area .4727 square inches, and ratio of dimensions in original section 2.12, give an average of 91.47 per cent. for the ratio of final percentages of thickness and width. The dotted curve through the corresponding spot is the probable curve for pieces 8 inches long and 1 inch wide. The average value for all the tests in that table is 91.92 per cent., with about the same ratio of dimensions in the original section as for the Cambria steel.

The difference in surface of the width and of the thicknesses, the pieces being planed out on two sides only, may possibly influence the effect above considered.

FRACTURE BY SHEAR.

It has been stated that rupture of the mild steels generally occurs by a sliding action, or shearing, on a quasi plane, or combination of planes, making a pretty definite angle with the direction of the straining force. Frequently the surface of fracture is sufficiently defined to admit of fairly accurate measurement, and a number of fractures of Cambria steel were so measured and the results tabulated. The mean angle of the fractured surface with the straining force as so measured is not 45° , as it would be if the material were perfectly isotropic when rupture occurs. There is reason to believe that this material is practically isotropic under strains considerably above the elastic limit, and even perhaps approaching tensile limit, but during necking the action of the flow produces a stringing of particles, so that the surface of the piece treated with acids shows a kind of fiber. This fiber should not, however, be confused with that developed by good fibrous iron. The union of one fiber or line of particles with adjacent ones is much more complete in the steel, in which there is no slag interposing between the fibers, while the iron is never without it.

How far the lack of isotropic quality at rupture will affect the disposition of conjugate stresses is as yet impossible to say; from the bearing of the results of independent tests upon the conclusion to be arrived at from an investigation of the stress under which fracture occurs on the assumption of isotropism, the effect is probably small.

* The six selected heats are 4674, 4678, 4681, 4682, 4684, 4686, the test plates for which were accidentally rolled too thick.

If P (Fig. 18) be the force producing principal stress (tensile) at the moment of fracture; A_r , the fractured area measured at right angles to the line of action of the force P ; and φ the mean angle of the fractured area with the line of force, then the mean shearing stress on the plane of fracture in a perfectly isotropic body will be given by

$$P_s = \frac{P}{2 A_r} \sin 2 \varphi, \text{ or } = \frac{P}{\frac{2 A_r}{\sin 2 \varphi}} \cdot$$

Let $A B C D$ (Fig. 19) be the fractured surface, approximately plane; $a b c d$, the corresponding area—commonly called the fractured area—at right angles to the line of force producing stress; Φ , the complement of the angle between the two planes, or the angle of $A B C D$, with the line of force.† The thicknesses ad , bc , on the edges, and ef at the middle of the fractured area are not equal, ef being especially less than the other two on account of the invariable hollow of the section towards the center. The value also of the angle made by the line of force with the edges AD and BC and with the corresponding center line EF is not generally the same. So that the mean value of the function

$$\frac{2 A_r}{\sin 2 \varphi}$$

must be obtained by integrating over the surface.

Accordingly, let t_1 , t_2 , t_3 and φ_1 , φ_2 , φ_3 be the values of the thickness and angle at G , I , and H , respectively; then, applying Simpson's rule for three ordinates, we have

$$\frac{2 A_r}{\sin 2 \varphi} = \frac{G H}{3} \left\{ \frac{t_1}{\sin 2 \varphi_1} + \frac{4 t_2}{\sin 2 \varphi_2} + \frac{t_3}{\sin 2 \varphi_3} \right\}$$

and

$$P_s = \frac{P}{\frac{G H}{3} \left\{ \frac{t_1}{\sin 2 \varphi_1} + \frac{4 t_2}{\sin 2 \varphi_2} + \frac{t_3}{\sin 2 \varphi_3} \right\}}$$

whence, by substituting the proper numerical values and performing the operations indicated, the numerical value of the shearing stress under which rupture occurred can be obtained for any measured fracture.

An interesting derived function is the mean angle of fracture, by which is meant the angle which upon being inserted with the ordinary fractured area in the function

$$\frac{2 A_r}{\sin 2 \varphi}$$

will give it the value obtained by integration.

The calculation in a particular case arranges itself as follows:

NUMERICAL EXAMPLE.

Piece 5221-2 in Table XXIX.

$$\begin{array}{rcl} t_1 \dots\dots & .329 \log. & = 9.51720 \\ 2\varphi_1 \dots\dots & .102^\circ \log. \sin. & = 9.99040 \\ \hline & & 9.52680 \end{array}$$

* See any standard text-book on the strength of materials.

† It makes no difference which of the two angles is used, since the sine of twice the angle is the same in either case.

Number corresponding = .33635..... $\times 1 = .33635$

$$\begin{array}{r} t_2 \dots .310 \log. = 9.49136 \\ 2\varphi_2 \dots 110^\circ \log. \sin. = 9.97299 \\ \hline 9.51857 \end{array}$$

Number corresponding = .32990..... $\times 4 = 1.31960$

$$\begin{array}{r} t_3 \dots .330 \log. = 9.51851 \\ 2\varphi_3 \dots 101^\circ \log. \sin. = 9.99195 \\ \hline 9.52656 \end{array}$$

Number corresponding = .33617..... $\times 1 = .33617$

$$\begin{array}{r} \hline 3) 1.99212 \\ \hline \end{array}$$

$$\begin{array}{r} .66404 \log. = 9.82219 \\ .973 \log. = 9.98811 \\ \hline \end{array}$$

Corresponding co-log. = .18970..... $\text{Log. } \frac{2A_f}{\sin 2\varphi} \dots \dots \dots 9.81030$

$$P \dots 31,000 \dots \log. = 4.49136$$

$$\log. P_s = 4.68106$$

$$P_s = 47,980 \text{ pounds per square inch.}$$

Mean angle.

$$\text{Co-log. } \frac{2A_f}{\sin 2\varphi} = .18970$$

$$\begin{array}{r} A_f \dots .3079 \log. = 9.48841 \\ 2 \log. = .30103 \\ \hline \end{array}$$

$$9.97914 \text{ corresponding to } 2\varphi = 107^\circ 37', \text{ or } \varphi = 53^\circ 48\frac{1}{2}'$$

Table XXIX. gives the results* of the tests with measurements of fractured area and derived quantities. The measurements for thickness of fractured section will give a very fair idea of the amount of hollow commonly found with this proportion of test piece. The less thickness at center is generally accompanied by the greater angle with the line of force, in twelve cases out of the fourteen the angle at the center exceeding the mean for the edges, and in only three is it exceeded by the angle at any edge. The mean angle of the surface with the line of force is seen to vary from $49^\circ 20'$ to $61^\circ 18'$, a range of 12° , and its probable average value is $53^\circ 40'$. From the fact that the angle at the center exceeds the values at the edges, it is probable that the mean angle for round pieces, breaking with a cup fracture, will slightly exceed this value.

* In the calculation of these results the methods proposed in this report have been adopted, so that certain columns differ from those in the table of tests for this steel.

TABLE XXIX.—Fracture by shear.

Heat.	Original section.		Fractured section.						Elastic limit per square inch.	Ultimate tensile strength per square inch.	Elastic ratio.	Final elongation.	Final width.	Mean final thickness.		Final area.	Modulus of elasticity.	Elongation at tensile limit.	Load at rupture.		Shearing stress produced by rupture on the area of fracture per square inch.	Ratio: Shearing stress divided by apparent tensile stress.
	Mark.	Width.	Thickness.	Area.	Width.	Thickness at edges and middle.	Angle of surface at edges and middle.	Mean angle of surface with line of force.						Area.	Per gauge.				Per square inch of final area.			
4879..	1	1.247	.436	5.437	.924	.310 .316 .307 .307 .322 .322 .315	53 15 53 45 53 45 53 15 48 30 48 30 49 30	53 58 53 45 53 45 53 15 48 30 48 30 49 30	2650 38,440 62,730	61.28 61.28 61.28 61.28 62.20 62.20 62.20	25.7 25.7 25.7 25.7 22.8 22.8 22.8	74.10 74.10 74.10 74.10 76.50 76.50 76.50	65.79 65.79 65.79 65.79 68.24 68.24 68.24	43.74 43.74 43.74 43.74 52.20 52.20 52.20	29,810,000 29,810,000 29,810,000 29,810,000 27,740,000 27,740,000 27,740,000	20.9 20.9 20.9 20.9 21.0 21.0 21.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4879..	2	1.246	.435	5.420	.953	.310 .316 .307 .307 .322 .322 .315	53 15 53 45 53 45 53 15 48 30 48 30 49 30	53 58 53 45 53 45 53 15 48 30 48 30 49 30	2829 39,490 63,489	62.20 62.20 62.20 62.20 63.77 63.77 63.77	22.8 22.8 22.8 22.8 26.8 26.8 26.8	76.50 76.50 76.50 76.50 74.96 74.96 74.96	68.24 68.24 68.24 68.24 66.98 66.98 66.98	52.20 52.20 52.20 52.20 50.20 50.20 50.20	27,740,000 27,740,000 27,740,000 27,740,000 26,280,000 26,280,000 26,280,000	21.0 21.0 21.0 21.0 22.2 22.2 22.2	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4879..	3	1.263	.431	5.539	.946	.310 .316 .306 .306 .329 .329 .315	53 15 53 45 53 45 53 15 48 30 48 30 49 30	53 58 53 45 53 45 53 15 48 30 48 30 49 30	2731 40,450 63,430	63.04 63.04 63.04 63.04 68.04 68.04 68.04	26.8 26.8 26.8 26.8 23.4 23.4 23.4	74.96 74.96 74.96 74.96 77.41 77.41 77.41	66.98 66.98 66.98 66.98 72.76 72.76 72.76	50.20 50.20 50.20 50.20 56.32 56.32 56.32	26,280,000 26,280,000 26,280,000 26,280,000 29,900,000 29,900,000 29,900,000	22.2 22.2 22.2 22.2 18.0 18.0 18.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4879..	4	1.261	.434	5.472	.938	.315 .315 .312 .312 .334 .334 .335	50 00 50 00 51 30 51 30 53 30 53 30 53 30	50 45 50 45 56 48 56 48 53 41 53 41 53 41	2750 40,200 63,770	63.04 63.04 63.04 63.04 68.04 68.04 68.04	23.4 23.4 23.4 23.4 24.7 24.7 24.7	74.36 74.36 74.36 74.36 77.41 77.41 77.41	67.55 67.55 67.55 67.55 72.76 72.76 72.76	50.25 50.25 50.25 50.25 56.32 56.32 56.32	27,900,000 27,900,000 27,900,000 27,900,000 29,630,000 29,630,000 29,630,000	22.0 22.0 22.0 22.0 18.0 18.0 18.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4907..	2	1.257	.440	5.530	.973	.310 .310 .310 .310 .310 .310 .310	52 10 52 10 52 10 52 10 52 10 52 10 52 10	52 45 52 45 53 41 53 41 53 41 53 41 53 41	62,500 38,340 62,500	61.35 61.35 61.35 61.35 61.35 61.35 61.35	27.0 27.0 27.0 27.0 27.0 27.0 27.0	74.74 74.74 74.74 74.74 74.74 74.74 74.74	69.01 69.01 69.01 69.01 69.01 69.01 69.01	51.58 51.58 51.58 51.58 51.58 51.58 51.58	25,130,000 25,130,000 25,130,000 25,130,000 25,130,000 25,130,000 25,130,000	20.0 20.0 20.0 20.0 20.0 20.0 20.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4908..	1	1.251	.417	5.217	.965	.305 .305 .300 .300 .300 .300 .300	50 00 50 00 52 30 52 30 52 30 52 30 52 30	50 45 50 45 53 41 53 41 53 41 53 41 53 41	2691 38,340 62,500	61.35 61.35 61.35 61.35 61.35 61.35 61.35	27.0 27.0 27.0 27.0 27.0 27.0 27.0	74.74 74.74 74.74 74.74 74.74 74.74 74.74	69.01 69.01 69.01 69.01 69.01 69.01 69.01	51.58 51.58 51.58 51.58 51.58 51.58 51.58	25,130,000 25,130,000 25,130,000 25,130,000 25,130,000 25,130,000 25,130,000	20.0 20.0 20.0 20.0 20.0 20.0 20.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4908..	2	1.254	.417	5.229	.936	.272 .272 .308 .308 .308 .308 .308	64 00 64 00 53 30 53 30 53 30 53 30 53 30	61 18 61 18 57 50 57 50 57 50 57 50 57 50	40,160 40,160 62,700 62,700 62,700 62,700 62,700	64.06 64.06 64.06 64.06 64.06 64.06 64.06	25.5 25.5 25.5 25.5 25.5 25.5 25.5	74.64 74.64 74.64 74.64 74.64 74.64 74.64	67.79 67.79 67.79 67.79 67.79 67.79 67.79	50.60 50.60 50.60 50.60 50.60 50.60 50.60	30,200,000 30,200,000 30,200,000 30,200,000 30,200,000 30,200,000 30,200,000	19.0 19.0 19.0 19.0 19.0 19.0 19.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4908..	4	1.251	.415	5.191	.921	.280 .285 .333 .333 .310 .310 .310	59 20 59 20 49 30 49 30 50 30 50 30 50 30	57 50 57 50 50 8 50 8 50 8 50 8 50 8	40,460 40,460 38,940 38,940 62,690 62,690 62,690	64.30 64.30 62.12 62.12 62.12 62.12 62.12	26.6 26.6 25.4 25.4 25.4 25.4 25.4	73.62 73.62 76.82 76.82 76.82 76.82 76.82	69.28 69.28 72.15 72.15 72.15 72.15 72.15	51.01 51.01 55.42 55.42 55.42 55.42 55.42	33,000,000 33,000,000 29,270,000 29,270,000 29,270,000 29,270,000 29,270,000	22.0 22.0 20.0 20.0 20.0 20.0 20.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4918..	2	1.242	.438	5.440	.954	.323 .323 .339 .339 .328 .328 .332	49 20 49 20 45 45 45 45 48 00 48 00 48 00	50 234 50 234 50 45 50 45 50 234 50 234 50 234	40,070 40,070 63,050 63,050 63,050 63,050 63,050	63.55 63.55 63.55 63.55 63.55 63.55 63.55	24.0 24.0 24.0 24.0 24.0 24.0 24.0	76.63 76.63 76.63 76.63 76.63 76.63 76.63	75.62 75.62 75.62 75.62 75.62 75.62 75.62	57.95 57.95 57.95 57.95 57.95 57.95 57.95	29,590,000 29,590,000 29,590,000 29,590,000 29,590,000 29,590,000 29,590,000	19.0 19.0 19.0 19.0 19.0 19.0 19.0	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4918..	3	1.245	.437	5.441	.964	.332 .332 .340 .340 .319 .319 .319	48 00 48 00 52 30 52 30 55 00 55 00 55 00	48 00 48 00 58 43 58 43 58 43 58 43 58 43	41,330 41,330 64,450 64,450 64,450 64,450 64,450	64.13 64.13 64.13 64.13 64.13 64.13 64.13	23.6 23.6 23.6 23.6 23.6 23.6 23.6	76.95 76.95 76.95 76.95 76.95 76.95 76.95	72.76 72.76 72.76 72.76 72.76 72.76 72.76	55.99 55.99 55.99 55.99 55.99 55.99 55.99	29,090,000 29,090,000 29,090,000 29,090,000 29,090,000 29,090,000 29,090,000	18.6 18.6 18.6 18.6 18.6 18.6 18.6	Per cent. Pounds.	Per square inch of final area.	Per cent. Pounds.	Ratio: Shearing stress divided by apparent tensile stress.		
4919..	2	1.245	.445	5.540	.963				64,450	64.13	23.6	76.95	72.76	55.99	29,090,000	18.6	31,400	101,200	48,287	74.93		

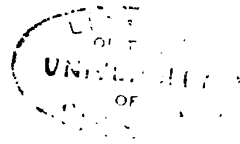
A curious counterpart of the fracture of mild steel by tension is found in that of short pieces of cast iron by true compression. Hodgkinson, experimenting on cast iron of the same manufacture in pieces of "length not more than about three times the diameter," finds that "the strength for a given base is pretty nearly the same," and in gun metals with low graphitic carbon the value is about that of the final strength of the mild steel per square inch of fractured area, from 100,000 to 115,000 pounds per square inch, although the distortion in the cast iron is of course small. Fracture of such pieces of cast iron takes place either by wedges sliding off, or by top and bottom forming pyramids and forcing out the sides, of which we find analogues in the plane and cup fractures of mild steel. Further, the angle of the wedge is nearly constant, a mean for 21 cylinders being $55^{\circ} 32'$, very nearly the angle which we have obtained for the fracture of mild steel flat pieces, and still nearer the probable value for rounds. Thus, besides the disposition of conjugate stresses being similar but opposite, fracture occurring by shearing in both cases, the very close accord of the angle of fracture points to analogous structure with respect to the resistance offered to the opposite stresses of tension and compression for the mild steel and cast iron respectively.

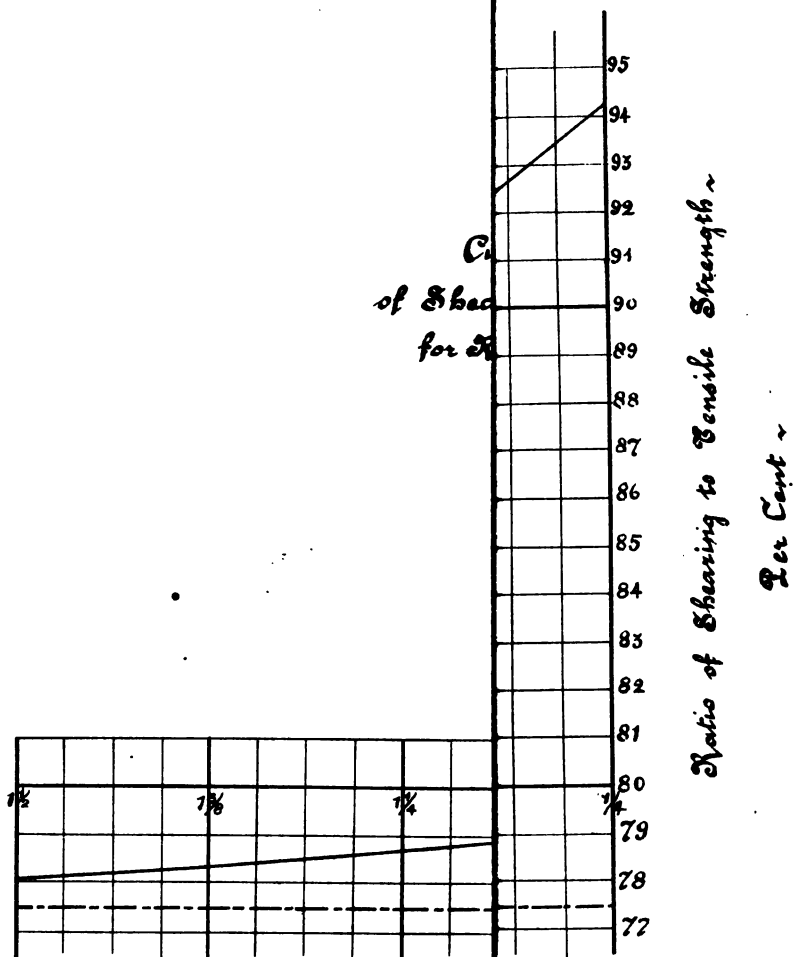
For the average quality of the steel represented in Table XXIX. the shearing stress on the fractured area at rupture was 48,730 pounds, with an average ratio to the ultimate tensile stress of 77.45 per cent. An average has been taken by tests on account of the complex way in which the results for the fracture are obtained and consequent liability to individual error, and also by heats, without regard to the number of tests, in order to take into account the variation of intrinsic quality. The probable average has been taken between the two. If we consider the method of obtaining it as satisfactory, it should represent the resistance of the material to unsupported or theoretical shearing, that is, shearing uninfluenced by the method of applying the forces.

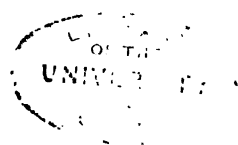
SHEARING STRENGTH OF RIVETS.

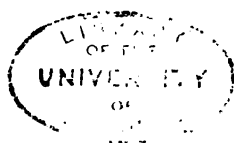
The shearing resistance of a rivet is seriously interfered with by the compression between the rivet and the bearing sides of the hole, the effect being to increase the shearing resistance offered per unit of area as the size of the rivet diminishes. Difference of quality between plate and rivet, proportion of thickness and diameter, and the sharpness of the edges of the hole, will also somewhat affect the shearing resistance. Under the ordinary conditions of ship and boiler work, the quality of plate and rivet being not very different—although the quality of the metal in the walls of the hole has frequently been affected by punching and insufficient riming—and the proportion of bearing and shearing areas being fairly uniform, it is known that the smaller rivets give considerably higher shearing resistance than larger ones of the same quality. The difference has, so far as we know, never been experimentally quantified, and it is believed that the following investigation will afford valuable information.

At the end of the tables of tests of rivets (pages 82 and 83) will be found the average ratio of shearing to tensile strength for each size tested. In combining the results of tests of $\frac{3}{4}$ -inch rivets, at Pittsburgh, with those for the same size at Chester, a representative value will be given to the former of double that due to the proportionate number of tests, inasmuch as they were carefully and independently obtained. In connection with the values so determined for the different sizes, we will

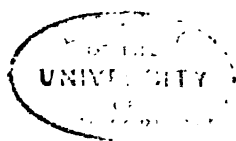




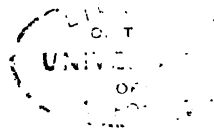


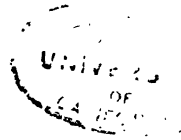


24 22 25 23 26 27 25 26 26 29



24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----





22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

assume that the value of the ratio of unsupported shearing obtained for the Cambria steel under tension will hold for the Bessemer steel of which the rivets were made. Although the two steels are of different intrinsic quality, there is yet not so much of assumption in this as would at first sight appear, since the value of the ratio is probably dependent on the physical structure of the metal, and within ordinary limits would be only influenced by quality as determined by tensile test, in so far as the difference of quality influences the physical structure. To this value of the ratio for unsupported shearing, that of large rivets or closely-fitting pins must approach as the size increases, so that it corresponds to the value for an indefinitely large rivet or pin. Further, it is believed that for diameters below $\frac{1}{2}$ inch the ratio rises less rapidly, though to what extent is not known, and it would have added much to the completeness of the results if $\frac{1}{4}$ -inch rivets had been tested under the same conditions.

Table XXX. contains the values obtained as described, and Plate XIII. is the graphic representation of the results. From this, the probable resistance of a rivet of given size, made from mild steel bar, showing certain results on tensile tests, may be obtained, and the variation due to size of rivet to be allowed in specifications exacting lower limits of both tensile and shearing resistances may be determined and appreciated.

TABLE XXX.

Size of rivet.	Ratio of shearing to tensile strength.
	<i>Per cent.</i>
$\frac{1}{4}$ inch	87.69
$\frac{1}{2}$ inch	84.84
$\frac{3}{4}$ inch	82.20
1 inch	81.27
Unsupported shearing .	77.45

In the consideration of individual results it must be remembered that the tensile test of rivet-bar is particularly liable to be affected by variation in the condition of finishing at the rolls, while the rivets also cool in the holes under variable conditions. In ship and boiler work, the strength of any part rarely depends on a single rivet, and average results are directly applicable.

STRAIN DIAGRAM.

In accordance with Section 12, Detailed Instructions to Inspectors of Materials (p. 398), tensile tests were made of certain pieces for comparison with similar tests made on the Rodman machine at the Washington naval arsenal, the corresponding strain being noted for each stress. From the reported results the strain diagrams in Plates XIV., XV., XVI., XVII., XVIII. were plotted.

The principal features of the strain diagram have been pointed out and partly discussed under the head of Straining the Piece. Complete information at and beyond tensile limit was not obtained for each steel, neither is the elastic limit as definitely determined in all cases as is desirable. In such cases the curves are drawn as appeared most probable, and are shown dotted where particularly uncertain. The extensions of pieces 4823-1 and 4823-2 Cambria steel, tested at Johnstown, were obtained with the electric contact micrometer, and although prob-

ably fairly correct below the elastic limit, at and beyond that point the method of clamping the index-arms to the piece with a considerable surface of contact seriously affects the readings, and it is believed that the irregularities shown by the spots are due rather to this defect in the micrometer* than to the behavior of the material. For this reason also the elastic-limit determinations for these pieces are perhaps somewhat untrustworthy, and not as accurate as if simpler methods of measurement had been used.

Table XXXI. contains particulars of the tests with certain derived quantities. As gauged by the ultimate tensile strengths, the steels are seen to be directly comparable, and while the tests of each manufacture are too few to admit of strictly quantitative comparison, the principal points can be noted.

TABLE XXXI.—Analysis of results of strain diagrams of special tensile tests.

Marks.	Manufacturer.	Tested at—				Original width.	Original thickness.	Original area.
			Carbon.	Manganese.	Phosphorus.			
			Pr. ct.	Pr. ct.	Pr. ct.	Inches.	Inches.	Sq. in.
486-C	Chester Rolling Mills	Chester Rolling Mills	*.12	*.37	.....	1.000	.5060	.5060
486-D	do	do	.12	.37	.....	1.000	.5070	.5070
36 U 1	Norway Steel and Iron Company.	Norway Steel and Iron Works.	*.16	*.36	.....	.985	.4220	.4160
36 U 3	do	do	.16	.36	.....	.996	.4250	.4230
P. S. 2	Cambria Iron Company	Phoenix Iron Works.	.14	.386	.082	1.003	.5120	.5135
P. S. 4	do	do	.16	.....	.079	1.000	.5156	.5156
4823-1	do	Cambria Iron Works.	.19	.600	.055	1.003	.4270	.4293
4823-2	do	do	.....	.....	.....	1.003	.4290	.4303
E. A. M. 1	Park Bro. & Co	Black Diamond Steel Works.	.....	.....	.....	.996	.4820	.4800
E. A. M. 2	do	do	.....	.....	.....	.997	.4750	.4735

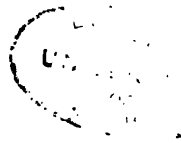
Marks.	Elastic limit.	Ultimate tensile strength.	Elastic ratio.	Final elongation.	Final area.	Area of strain diagram.	Work required to break a bar of 1 square inch sectional area 8 inches long.	Ratio—Ult. T. S. X Elong
	Lbs. per sq. in.	Lbs. per sq. in.	Per ct.	Per ct.	Per ct.	Lbs., per ct.	Foot-lbs.	Per ct.
486-C	31,600	63,930	49.43	24.40	56.70	(f)	.....	.....
486-D	31,550	63,800	49.45	25.31	44.30	(f)	.....	.....
36-U 1	32,500	63,460	51.21	27.50	.....	1,571,000	10,473	90.16
36 U 3	32,150	62,244	51.66	24.35	.....	1,367,000	9,116	90.24
P. S. 2	38,800	63,776	60.84	24.94	56.40	1,429,200	9,528	89.85
P. S. 4	38,000	62,258	61.04	27.05	53.92	1,530,900	10,205	90.92
4823-1	42,500	63,590	66.84	26.40	49.60	1,513,800	10,092	90.16
4823-2	44,000	63,470	69.32	24.40	51.50	1,412,400	9,416	91.20
E. A. M. 1	36,250	62,800	57.73	23.25	.....	(f)	.....	.....
E. A. M. 2	39,000	64,370	60.59	26.40	.....	(f)	.....	.....

* Heat determinations.

† Strain diagram incomplete.

‡ Broke through flaw.

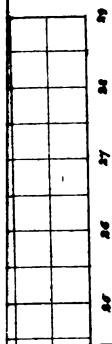
* This defect in the electric contact micrometer has been carefully remedied in a new instrument designed and in use by Mr. C. A. Marshall, engineer of tests, Cambria Iron Works, by using point bearings only to secure the gauge to the piece, the index-arms being steadied by springs with roller bearings against the piece. This new instrument is quite perfect.



	21
	22
	23
	24
	25
	26
	27
	28
	29
	30
	31
	32
	33
	34
	35
	36
	37
	38
	39
	40
	41
	42
	43
	44
	45
	46
	47
	48
	49
	50
	51
	52
	53
	54
	55
	56
	57
	58
	59
	60
	61
	62
	63
	64
	65
	66
	67
	68
	69
	70
	71
	72
	73
	74
	75
	76
	77
	78
	79
	80
	81
	82
	83
	84
	85
	86
	87
	88
	89
	90
	91
	92
	93
	94
	95
	96
	97
	98
	99
	100



annealed



25

26

27

28

29



annealed

		••
		••
		••
		••
		••
		••
		••
		••
		••
		••

The most notable and important difference appears in the elastic ratio, which has a very low value for the Chester and Norway steels, 49.44 and 51.43 per cent., respectively. These ratios are both perhaps somewhat lower than usual, the average elastic ratio of ten heats of Norway steel (unannealed), including that given by these tests, being 53.74 per cent. Both of these are "pig and scrap" steels and contain probably not above 0.05 per cent. of phosphorus. They are also noticeable for the almost complete lack of sudden extension at elastic limit, and it is not thought that the cold straightening to which the pieces had been subjected is altogether sufficient to account for this. In the Norway steel, whose tests with strain curves are given under the head of "annealing," this peculiarity is by no means so marked, although the curve at elastic limit is not so flat as is commonly the case. The Black Diamond steel, reported as made by the "pig and scrap" process and with low phosphorus, shows the higher value for elastic ratio of 59.16 per cent., very nearly approaching the value of 60.94 for the "pig and ore" Cambria steel of comparatively high phosphorus from the deck-beam web. As has been remarked, the values for the Cambria steel from the flat are somewhat unreliable; if correct as taken, they are evidence of comparatively cold finishing or rapid cooling after finishing, as the phosphorus, which notably raises the elastic ratio, is low. The comparatively high manganese of these pieces may, however, have influenced the result.

Although the elastic limits of the Chester and Norway steels are low, the extensions immediately following the elastic limit are much less than for the other two steels, so that no work area is lost.

The behavior at and beyond tensile limit is probably very similar for all the steels, except the Cambria pieces P. S. 2 and 4, which appear to show a longer necking or flow, with correspondingly flatter curves after tensile limit. The exact nature of the curves beyond tensile limit is not determined; it is generally taken somewhat as shown in these curves, but is probably influenced by the rapidity and uniformity of extension. In the strain diagrams of Norway steel, Plates XIX., XX., and XXI., this part of the curve was obtained by three determinations for each piece, and the result is shown as a comparatively straight line. The same straight line of flow was obtained with some shaft metal tested by the same inspector.

The area of the strain diagram is a measure of the work expended in breaking the piece, and, to a certain extent, may be taken as a measure of the capacity of the material for absorbing mechanical energy. Only six of the strain diagrams of tests made for comparison of machines are sufficiently complete to be integrated, giving an average value of 1,470,700 pounds per cent., or 9,805 foot-pounds, of work expended in breaking a bar of one square inch sectional area, 8 inches long, the ductilities being on the basis of the actual areas of the pieces tested. Similar results for nine heats of Norway steel unannealed, given in Table XXXVII., are 1,529,336 pounds per cent., or 10,192 foot-pounds. The probable average value for all the material accepted, as given in the General Summary, p. 442, is 9,685 foot-pounds. With the increased ductility from the larger sectional area of one square inch, it appears probable that about 10,000 foot-pounds will, on the average, be actually necessary to break the standard bar of general ship quality. Although the conditions are largely arbitrary, it may be interesting to state that this denotes a capacity to absorb energy at the rate of 4,424 foot-tons per ton weight, assuming one cubic foot to weigh 488.3 pounds.

It will be observed from the last column of Tables XXXI. and XXXVII. that the area of the strain diagrams would appear to be a pretty con-

stant fraction of the product of the extreme dimensions, the fraction averaging 90.26 per cent. for the six pieces in Table XXXI., with small variation, and 88.42 per cent. for the nine heats of unannealed Norway steel in Table XXXVII., though the curve of flow in the latter is drawn differently and so as to give less work area. As ordinarily drawn, the area of the strain diagram for steel of this quality may very fairly be taken as 90 per cent. of the product of tensile strength and ductility in an 8-inch piece of about one-half square inch original sectional area. Accordingly, admitting that capacity to absorb energy is the best single measure of intrinsic quality, we may use instead, as a conventional measure, the product of tensile strength by ductility, since the ratio of the two is practically constant. The average value of this function, under the name of "efficiency number," for all the steels delivered, is given in the General Summary, p. 76, and may be taken as a basis of specification.

This conception of classifying structural metal by its ultimate resilience or work capacity, and conventionally by the efficiency number, was first propounded by Tetmajer,* who gives as a limiting value of the efficiency number for the standard bar of malleable cast metal (iron or steel), 1 foot long and 1 square inch sectional area, 12,250 foot-pounds. The average value for the steel delivered under this inspection, in such a standard piece, would be about 14,750 foot-pounds. We have pointed out the advantages of the method, and sought to establish it for ship and boiler metal.

*Eisenbahn, Zurich, October 15, 1881, p. 92. Also Thurston's Materials of Engineering, Part II., p. 358-359.

Tables of stress and strain.

CAMBRIA SHIP STEEL.

[Pieces taken from web of 8-inch deck beam. Tested on Riehle machine at Phoenix Iron Works.
Measurements of strain taken with fine needle- and pencil-point dividers.]

Piece P. S. 2.			Remarks.	Piece P. S. 4.			Remarks.
Stress applied per square inch.	Extensions.			Stress applied per square inch.	Extensions.		
<i>Pounds.</i>	<i>Inches.</i>	<i>Per ct.</i>	38,800 pounds E. L.	<i>Pounds.</i>	<i>Inches.</i>	<i>Per ct.</i>	E. L.
10,000-18,000	(*)	(*)		10,000-18,000	(*)	(*)	
20,000	(†)	(†)		20,000	(†)	(†)	
20,000-38,000	(‡)	(‡)		20,000-38,000	(‡)	(‡)	
38,000	.02	.25		38,000	.053	.66	
40,000	.165	2.06		40,000	.170	2.13	
42,000	.185	2.31		42,000	.217	2.71	
44,000	.220	2.75		44,000	.252	3.15	
46,000	.255	3.19		46,000	.286	3.58	
48,000	.300	3.75		48,000	.320	4.00	
50,000	.350	4.37		50,000	.375	4.69	
52,000	.405	5.06		52,000	.427	5.34	
54,000	.440	5.50		54,000	.530	6.63	
56,000	.562	7.02		56,000	.633	7.91	
58,000	.675	8.44		58,000	.750	9.38	
60,000	.820	10.25		60,000	.920	11.50	
62,000	1.085	13.56		62,000	1.224	15.30	
63,776	1.450	18.13	Ultimate strength.	62,258	1.264	27.05	Ultimate strength.
58,440	1.995	24.94	Final load and elongation.				Final elongation.

* Not appreciable.

† First appreciable.

‡ Not accurately measurable.

Tables of stress and strain—Continued.

CAMBRIA SHIP STEEL.

[Pieces taken from 6 inches by $\frac{7}{8}$ inch flat. Tested on Gill machine at Cambria Iron Works. Measurements of strain up to stress of 56,000 pounds per square inch taken with Olsen electric contact micrometer.]

Piece 4823-1.					Piece 4823-2.				
Stress applied per square inch.	Extensions.		Corresponding value of E.	Remarks.	Stress applied per square inch.	Extensions.		Corresponding value of E.	Remarks.
	Lbs.	In. Pr. ct.				Lbs.	In. Pr. ct.		
10,000.	00280	.....	28,570,000		10,000.	00295	.....	27,120,000	
12,000.	00340	.....	28,240,000		12,000.	00350	.....	27,425,000	
14,000.	00400	.....	28,000,000		14,000.	00405	.....	27,650,000	
16,000.	00460	.....	27,825,000		16,000.	00460	.....	27,830,000	
18,000.	00515	.....	27,960,000		18,000.	00520	.....	27,690,000	
20,000.	00570	.....	28,070,000		20,000.	00575	.....	27,825,000	
22,000.	00620	.....	28,385,000		22,000.	00635	.....	27,715,000	
24,000.	00680	.....	28,235,000		24,000.	00700	.....	27,430,000	
26,000.	00735	.....	28,295,000		26,000.	00760	.....	27,370,000	
28,000.	00790	.....	28,355,000		28,000.	00820	.....	27,320,000	
30,000.	00845	0.106	28,400,000		30,000.	00890	0.111	26,965,000	
32,000.	00900	.....	28,445,000		32,000.	00965	.....	26,525,000	First E. L.
34,000.	00955	.....	28,480,000		34,000.	01100	.....	24,725,000	
36,000.	01020	.....	28,230,000	First E. L.	36,000.	01240	.....	
38,000.	01105	.....			38,000.	01445	.....	
40,000.	01380	0.173			40,000.	01900	0.237		
42,000.	01753	0.220			42,000.	02705	0.346		
				42,500 pounds E. L.	44,000.	04365	0.546		E. L.
44,000.	09400	1.175			46,000.	10670	1.334		
46,000.	26565	3.321			48,000.	27630	3.454		
48,000.	41915	5.240			50,000.	31690	3.961		
50,000.	47725	5.966			52,000.	35960	4.495		
52,000.	51405	6.426			54,000.	41885	5.236		
54,000.	57420	7.180			56,000.	48145	6.018		
56,000.	65325	8.166			58,000	.....	8.700		
58,000	.....	8.700			60,000	.....	10.500		
60,000	.....	10.500			62,000	.....	13.000		
62,000	.....	.....			63,470	.....	20.25		Ultimate strength.
63,590	20.50	.....		Ultimate strength.	53,250	.....	24.40		Final load and elongation.
51,250	26.40	.....		Final load and elongation.					

Tables of stress and strain—Continued.

CHESTER SHIP PLATE.

Tested on Riehle machine at Chester Rolling Mills. Measurements taken with Brown & Sharp's micrometer gauge.]

Piece 486 C.			Piece 486 D.		
Stress applied per square inch.	Extensions.		Stress applied per square inch.	Extensions.	
<i>Pounds.</i>	<i>Inches.</i>	<i>Per ct.</i>	<i>Pounds.</i>	<i>Inches.</i>	<i>Per ct.</i>
10,000	.....	.....	10,000	.....	.....
13,950	.....	.....	13,945	.....	.....
21,880	.....	.....	17,890	.....	.....
25,810	.....	.....	21,835	.....	.....
29,765	.02	.25	25,780	.....	.....
			29,725	.02	.25
33,715	.07	.87	33,670	.07	.87
37,667	.12	1.50	37,615	.12	1.50
41,620	.16	2.00	41,555	.17	2.12
45,572	.23	2.87	45,500	.23	2.87
49,525	.32	4.00	49,450	.31	3.87
53,473	.44	5.50	53,390	.45	5.62
57,425	.61	7.62	57,335	.62	7.75
61,380	.92	11.50	61,280	.93	11.62
63,930	.....	.....	63,800	.....	.....
.....	1.952	24.40	.....	2.025	25.31

31,600 pounds E. L.

31,550 pounds E. L.

Ultimate strength.
Final elongation.

Ultimate strength.
Final elongation.

Tables of stress and strain—Continued.

NORWAY SHIP PLATE.

[Tested on Riehle machine at Norway Steel and Iron Works. Measurements taken with Brown & Sharp's micrometer gauge held to the piece. Measured length for elongation, piece 36 U 1=8.001; piece 36 U 3=8.002.]

Piece 36 U 1.			Piece 36 U 3.		
Stress applied per square inch.	Extensions.		Stress applied per square inch.	Extensions.	
Pounds.	Inches.	Per ct.	Pounds.	Inches.	Per ct.
10,000	.002	.....	10,000	.001	.....
11,923	.003	.....	12,009	.002	.....
13,846	.004	.....	14,018	.003	.....
15,769	.006	.....	16,028	.006	.....
17,692	.009	.....	18,037	.006	.....
19,615	.011	.14	20,047	.007	.09
21,538	.013	.16	22,056	.008	.10
23,461	.014	.17	24,066	.009	.11
25,384	.016	.20	26,075	.011	.14
27,307	.021	.26	28,085	.013	.16
29,230	.028	.35	30,094	.016	.20
31,153	.032	.40	32,104	.020	.26
32,500 pounds E. L.			34,113	.052	.65
			36,122	.086	1.07
			38,132	.108	1.35
			40,141	.134	1.68
			42,151	.166	2.08
			44,160	.196	2.45
			46,170	.241	3.01
			48,179	.284	3.55
			50,189	.341	4.26
			52,198	.404	5.05
33,076	.046	.58	54,209	.479	5.99
35,000	.071	.89	56,217	.582	7.28
36,923	.094	1.18	58,226	.748	9.35
38,846	.114	1.44	60,236	.943	11.79
40,769	.140	1.75	62,244	1.624	20.30
42,692	.168	2.10	52,009	1.948	24.85
44,615	.200	2.50	Ultimate strength. Final load and elongation.		
46,538	.241	3.01			
48,461	.288	3.60			
50,384	.335	4.19			
52,307	.389	4.86	Ultimate strength. Final load and elongation.		
54,230	.469	5.86			
56,153	.572	7.15			
58,076	*.613	7.65			
60,000	.892	11.15	Ultimate strength. Final load and elongation.		
61,923	1.294	16.17			
63,460	1.898	23.72			
65,884	2.200	27.50			

* .713 probably.

† 8.00 probably.

TESTS FOR COMPARISON OF MACHINES.

The tests made on the Rodman machine at the Washington Naval Arsenal in accordance with section 12, Detailed Instructions, while supplying much interesting information, are of little use for the purpose intended. From some misunderstanding as to the instructions, they were not made in the same way as the corresponding tests at the works, but after the ordinary method of testing adopted there for ordnance metal. The elastic limit was determined by successive application and removal of stress, noting the first permanent set; thence continuously to tensile limit where elongation and resisting area are measured. In Table XXXII. of these tests, a derived column is given of what would be the volume of the piece at this point if the resisting area were uniform all along the piece and equal to that measured. Low percentage of volume shows unequal extension, and corresponding contraction of area, along the length, and such lack of uniformity is noticeable in the Norway pieces and especially in one piece of Black Diamond Steel, which also gives extremely low elastic limit. Such results, with well-shaped pieces, show lack of homogeneous quality of the metal. It is a curious and suggestive fact that the values of the percentage of volume at tensile limit follow exactly the order of final elongation, adding somewhat to the argument as to the finality of the condition of the piece at tensile limit. At rupture the stress was noted, and notwithstanding the varying ductilities and contractions of area, the stress per square inch of actual area is seen to be very uniform. The thickness of final area was taken as the mean of three measurements, one at each edge and at the middle. The other leading features derived from this table are referred to under appropriate headings.

TABLE XXXII.—Tests for comparison of machines made on Rodman machine at the Washington Naval Arsenal.

Marks.	Manufacturer.	Carbon.			Manganese.			Phosphorus.			Original width.	Original thickness.	Original area.	Elastic limit per square inch.*	Elastic ratio.	Tensile strength.		Distortion at tensile limit.			Stress at rupture.		Final elongation.	Final width of original.	Final thickness of original.	Final area of original.	Remarks.
		p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	in.	sq. in.	lbs.						per ct.	lbs.	on original area per square inch.	on actual fracture per square inch.	Restisting area.	Corresponding product for volume.	On original area per square inch.					
G. O.	Chester Rolling Mills.	12. 37	12. 37	12. 37	12. 37	12. 37	12. 37	1.005	.507	.5095	30,714	50.64	60,650	75,630	18.95	80.20	93.38	49,250	111,030	25.17	69.85	63.51	44.36	(Stress of 35,175 pounds per square inch remained on for 2 hours.)			
G. I.	do.	12. 37	12. 37	12. 37	12. 37	12. 37	12. 37	1.004	.510	.5120	32,520	53.45	60,845	74,270	18.40	81.94	97.01	50,485	108,020	25.60	70.31	66.47	46.74				
D. O. 36 U. 2 ..	Norway Steel and Iron Company.	16. 36	16. 36	16. 36	16. 36	16. 36	16. 36	.995	.422	.4198	33,104	52.65	62,890	81,320	18.47	77.34	91.61	52,210	110,970	22.62	72.37	66.59	48.19				
D. I. 36 U. 4.	do.	16. 36	16. 36	16. 36	16. 36	16. 36	16. 36	.990	.421	.4167	34,310	54.36	63,115	79,340	17.89	79.56	93.79	52,790	111,470	22.62	71.73	66.03	47.37				
E. A. M. 3 O.	Park, Brother & Co. ....	.....	.....	.....	.....	.....	.....	1.000	.489	.4890	34,867	56.45	61,765	78,010	18.76	79.18	94.03	51,120	108,470	25.06	71.80	65.64	47.13
E. A. M. 4 I.	do.	.....	.....	.....	.....	.....	.....	.999	.491	.4905	25,090	40.76	63,025	81,995	15.31	76.87	88.63	53,000	108,360	19.13	72.78	67.22	48.91
G. D. 1, No. 1.	Cambria Iron Company.	15. 39	15. 39	15. 39	15. 39	15. 39	15. 39	1.000	.516	.5160	34,459	56.63	60,855	74,130	20.05	82.10	98.55	48,070	114,540	29.34	68.10	61.64	41.96				
G. D. 2, No. 3.	do.	15. 39	15. 39	15. 39	15. 39	15. 39	15. 39	.998	.516	.5156	35,245	58.55	60,200	75,120	22.01	80.14	97.77	47,000	112,400	32.00	67.84	61.64	41.81				
B. 4823-1	do.	19. 600	19. 600	19. 600	19. 600	19. 600	19. 600	1.006	.439	.4316	30,625	62.64	63,290	81,130	21.56	77.98	94.77	49,825	112,550	26.88	70.08	63.17	44.27				
B. 4823-2	do.	19. 600	19. 600	19. 600	19. 600	19. 600	19. 600	1.002	.428	.4288	38,485	59.47	64,720	78,790	19.20	82.15	97.91	50,270	108,650	25.25	70.36	66.36	46.69				

* First elastic limit, corresponding to first appreciable permanent set.

Table XXXIII. is a comparison of results on the different testing-machines with those on the Rodman, two tests for each steel on each of the two machines compared. On account of the difference of methods of testing and the absence of comparative strain diagrams, no nice comparisons can be attempted. On the basis of ultimate tensile strength the Norway and Cambria machines give practically the same results as the Rodman; all the others read too high. But a comparison of ductilities and efficiency numbers obtained shows such variation in some cases as to throw serious doubts on the value of any comparison, while illustrating the necessity of a standard method of making the test. The most remarkable differences are the diminished ductility of the Norway metal and the increased ductility of the Cambria metal from the Phoenix Iron Works in the tests on the Rodman. The reduction of efficiency number of the one is about equal to the increase for the other, so that these steels were affected in exactly opposite ways by the difference of method in testing.

It may be safely stated that none of the machines differ sufficiently from the standard Rodman for the difference to be detected by any such method of comparison, and dead-weight test will alone show such differences as can ordinarily be expected to exist.

TABLE XXXIII.—Comparative tensile tests of the same material on the machine at the works and on the standard Rodman.

Manufacturer.	Tested at—	Testing-machine.	Carbon.	Manganese.	Phosphorus.	Original width.	Original thickness.	Original area.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Elastic ratio.	Final elongation.	Final area.	Efficiency number.
Chester Rolling Mills...	Chester Rolling Mills...	Riehlé, 100,000 pounds...	Per ct. .12	Per ct. .37	Per ct. .08	Inch. 1.000	Inch. .5085	Sq. in. .5085	Pounds. 31,575	Pounds. 63,865	Per ct. 49.45	Per ct. 24.86	Per ct. 50.50	1,587,300
Do.....	Washington	Rodman .....	.12	.37	.08	1.000	.5085	.5108	*31,617	60,748	52.05	25.34	45.55	1,538,950
Norway Steel and Iron Company.	Norway Steel and Iron Works.	Riehlé, 50,000 pounds...	.16	.36	.055	.991	.4235	.4195	32,325	62,852	51.44	25.93	.....	1,630,250
Do.....	Washington	Rodman .....	.16	.36	.055	.992	.4215	.4183	*33,707	63,003	53.50	22.72	47.78	1,431,350
Park, Brother & Co.....	Black Diamond Steel Works.	Riehlé, 50,000 pounds...	.....	.....	.....	.996	.4765	.4767	37,625	63,585	59.16	24.83	.....	1,579,600
Do.....	Washington	Rodman .....	.....	.....	.....	1.000	.4900	.4898	*30,278	62,395	48.60	22.10	48.02	1,377,300
Cambria Iron Company...	Phoenix Iron Works ..	Riehlé, 150,000 pounds...	.15	.39	.08	1.001	.5138	.5145	38,400	63,017	60.94	26.00	55.16	1,637,150
Do.....	Washington	Rodman .....	.15	.39	.08	.999	.5160	.5155	*34,852	60,528	57.59	30.67	41.89	1,455,900
Do.....	Cambria Iron Works ..	Gill, 100,000 pounds...	.19	.60	.055	1.003	.4280	.4288	43,250	63,530	68.08	25.40	50.55	1,613,650
Do.....	Washington	Rodman .....	.19	.60	.055	1.004	.4285	.4302	*39,055	63,990	61.06	26.06	45.48	1,667,250

* First elastic limit, corresponding to first appreciable permanent set.

ANNEALING.

The Board's experience with annealing has been of a contradictory nature; still it throws some light on the subject and introduces some important facts as to the possible effect of the process as commonly carried out. The process of annealing boiler-plate at the works consists in slowly heating the plates in batches in large furnaces to a cherry-red temperature,* and allowing them to cool slowly on the bed-floor of the foundry, usually under a layer of ashes. Ordinary precautions are taken to insure uniform heating and subsequent cooling of all parts of the plate, and to avoid all possibility of overheating in any part.

During the ordinary inspection, certain heats were annealed wholly or in part, either to bring up deficient ductility in metal intended for ship plate or to lower the tensile strength of metal just above the limit for boiler material. Table XXXIV. gives the corresponding results of tests, from which it appears that the average effect on the Chester steel is a reduction of about 5 and 19 per cent., respectively, in the original values for tensile strength and final area, and an increase of 12.5 per cent. in the original value for ductility in 8 inches, the average original area being practically identical for both conditions. The very considerable decrease in final area will account for much of the increase in final elongation, leaving that element of extension which is practically uniform along the length approximately unchanged. We have then a considerable diminution of tensile strength and increase of capacity for local distortion. It will be observed also that, roughly speaking, these changes are greatest in those heats which originally appeared the softest. Especially noticeable is heat 640, soft and not annealed for any defect of quality. The increase of efficiency number in all except this heat should be a measure of the improvement effected by the process, provided there has been no essential molecular change. In heat 640 this number remains practically the same.

* To make annealing thoroughly effective in removing internal strains, this temperature should not be less than that at which the plate was finished

TABLE XXXIV.—Showing effect of annealing various heats of steel.

CHESTER STEEL.

Heat.	Condition.	Carbon.	Manganese.	Phosphorus.	Original width.	Original thickness.	Original area.	Ultimate tensile strength per square inch.	Final elongation.	Efficiency number.	Final area.	Number of tests.	Decrease in tensile strength.		Increase in final elongation.		Decrease in final area.	
													Per square inch.	Original value.	In 8 inches.	Per ct.	Original value.	Per ct.
463	Unannealed	Per ct.	Per ct.	Per ct.	Inches.	Inches.	Sq. in.	Pounds.	Per ct.	1,464,500	51.85	2+	Pounds.	Per ct.	Per ct.	Per ct.	Original value.	Per ct.
463	Annealed	.....	.....	.....	1.211	.4840	.6859	65,383	22.40	1,490,000	46.70	2+	1,033	1.58	0.60	2.68	5.15	9.93
619	Unannealed	.....	.....	.....	1.230	.4965	.6112	64,350	23.00	1,620,700	59.67	3	3,817	6.05	2.65	10.31	15.57	26.40
619	Annealed	.16	.36	.059	1.170	.6090	.7018	63,067	23.70	1,679,400	44.10	2	4,380	7.42	2.20	7.84	12.85	25.91
640	Unannealed	.13	.30	.049	1.258	.4900	.6162	59,000	28.05	1,652,700	49.60	2	2,883	4.84	4.62	23.16	9.33	15.81
640	Annealed	.....	.....	.....	1.724	.7413	.5362	54,620	30.25	1,326,600	59.00	2	8,482	5.46	4.63	18.63	7.80	16.94
680	Unannealed	.16	.31	.....	1.236	.4890	.6044	66,500	18.95	1,563,000	49.67	3	3,119	5.17	2.94	12.52	10.14	18.94
680	Annealed	.....	.....	.....	1.182	.5293	.6256	63,617	24.57	1,585,300	46.05	2	3,119	5.17	2.94	12.52	10.14	18.94
684	Unannealed	.13	.32	.....	1.194	.5000	.5968	63,800	24.85	1,778,000	38.25	4	3,119	5.17	2.94	12.52	10.14	18.94
684	Annealed	.....	.....	.....	.744	.7198	.5355	60,318	28.48	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average.....																		

BLACK DIAMOND STEEL.

610	Unannealed	.....	.....	.....	1.264	.4180	.5280	67,680	22.84	1,545,600	53.90	4	.....	.....	.....	.....	.....	.....
610	Annealed	.....	.....	.....	1.235	.4350	.5370	64,430	26.52	1,708,500	47.40	4	.....	.....	.....	.....	.....	.....

TABLE XXXV.—Showing effect of annealing certain plates intended for Chicago's boilers.

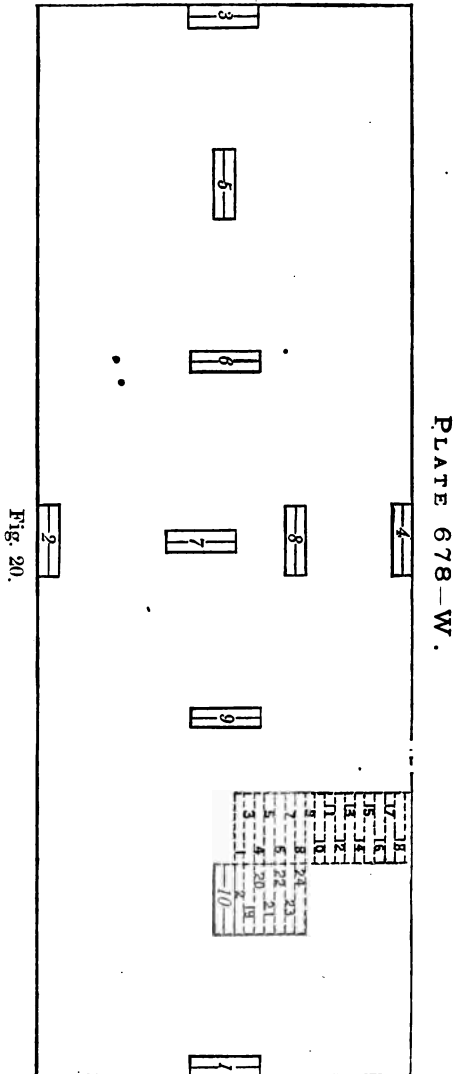
Heat.	Original heat tests.						Annealed plates.						Differences.		
	Carbon.	Manganese.	Original width.	Original thickness.	Original area.	Ultimate tensile strength per square inch.	Final elongation.	Final area.	Per ct.	Final elongation.	Per ct.	Final area.	Decrease of tensile strength per square inch.	Increase of final elongation in 8 inches.	Decrease of final area in per cent. of original area.
671	Per ct.	Per ct.	Inch.	Inch.	Sq. inch.	Pounds.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Pounds.	Per ct.	Per ct.
	.13	.31	1.213	.482	.5946	61,600	30.0	42.0	671-O.	1.035	.657	54,000	54,000	27.0	36.0
	1.200	.482	.5784	62,400	25.9	47.0	671-F.	1.025	.662	53,000	53,000	27.2	34.0
	671-E.	1.143	.617	53,170	53,170	29.8	38.5
673	671-Q.	1.190	.617	52,700	52,700	29.8	37.7
	671-Q.	.932	.580	56,400	56,400	28.4	35.7
	671-Q.	1.020	.585	54,130	54,130	32.1	38.0
	673-R.	1.064	.587	54,400	54,400	32.0	37.1
675	673-R.	1.036	.580	55,000	55,000	28.7	35.8
	673-T.	1.040	.565	57,400	57,400	30.7	39.3
	673-U.	1.020	.600	53,600	53,600	31.0	38.7
	673-U.	1.015	.600	53,500	53,500	28.3	37.7
677	675-S.	1.038	.575	54,970	54,970	28.4	39.2
	675-S.	1.038	.575	54,640	54,640	27.6	38.8
	675-X.	1.015	.595	53,020	53,020	30.5	35.0
	675-X.	1.175	.575	54,300	54,300	29.8	39.0
679	678-N.	1.040	.600	53,000	53,000	29.5	36.5
	678-N.	1.040	.600	53,400	53,400	30.7	38.3
	678-W.	1.155	.615	53,750	53,750	29.3	42.3
	678-W.	1.125	.620	52,600	52,600	28.7	36.7
Average of four heats															
						60,588	29.54	42.44					6,680	— .06	4.75

The single annealed heat of Black Diamond steel shows results very similar to the average for the Chester metal.

Certain sheets in the externally fired boilers of the Chicago besides bearing the shell stresses are exposed to the action of the flame, so that it was deemed advisable to carefully anneal them. The heat tests in the unannealed condition had been very excellent—from 59,700 pounds, with 29.65 per cent. stretch (efficiency number 1,770,105) to 62,000 pounds with 27.95 per cent. stretch (efficiency number 1,732,900)—so that there seemed amply sufficient margin of tensile strength to allow for annealing. The test pieces were cut from the side of each plate and annealed with it. The results of the corresponding tests are compared with the original heat tests in Table XXXV. The average loss of tensile strength, 6,680 pounds, very much exceeded what was to be expected, and, while accompanied by considerable diminution of flual area, the final elongation remains practically unchanged, so that the percentage of uniform stretch along the length has been probably diminished. The average efficiency number will be found to have seriously diminished. The annealing had effected a radical change in the material, and so reduced the tensile strength that the plates could not be used.

The process has not even produced uniformity in the same plate, 673—T showing 3,800 pounds difference between the two tests. It was accordingly decided to examine what differences existed in one of the plates of lowest tensile strength. Plate 678 W being selected, double pieces were cut out for test from symmetrically opposite portions of the plate, both with and across the direction of rolling, and numbered from 1 to 10. One of each pair of pieces was shaped as usual, and the other was rimmed out to the groove form.* G and C denote with and across the grain respectively, and symmetrically opposite pieces are placed together in the table, the better to indicate variation of quality.

* From the section numbered 10, the pieces were subsequently taken for the tests on the influence of length of test piece, and are shown dotted, numbered 1 to 24.



The average of the five tests with the grain is 54,521 pounds tensile strength, and 28.76 per cent. elongation, as compared with 53,050 pounds and 29 per cent. of the two pieces annealed with the plates. The maximum difference of tensile strength with the grain is 5,200 pounds, between pieces G2 and G4, and the lowest value 52,100 pounds. The average tensile strength across the grain is 55,530 pounds, or 1,000 pounds in excess of that with the grain, and with slightly less variation. The results in the groove form show differences in about the same proportion, though not for the same portions of the plate. Thus the lowest tensile strength in the groove form is in piece C1, side by side with that showing the highest value in the 8-inch length.

TABLE XXXVI.—*Tests for homogeneity of one of the annealed plates intended for Chicago's boilers.*

Marks.	8-inch length.						Groove form.				
	Original width.	Original thick-ness.	Original area.	Ultimate tensile strength.	Final elongation.	Final area.	Original width.	Original thick-ness.	Original area.	Ultimate tensile strength.	Final elongation.*
C 1.....	1.063	.662	.6736	57,300	29.1	46.8	.640	.675	.432	59,500	27.5
C 3.....	1.123	.668	.7501	52,790	31.2	43.1	.600	.668	.401	60,200	25.0
G 5.....	1.095	.690	.7227	54,780	30.3	41.0	.609	.680	.414	65,450	29.0
G 10.....	1.000	.688	.6680	55,588	30.9	44.8	.646	.666	.430	62,000	30.0
C 6.....	1.012	.664	.6720	55,350	27.5	46.9	.604	.680	.411	65,000	29.5
C 9.....	1.071	.675	.7229	54,910	29.0	51.0	.630	.670	.422	63,000	26.3
G 2.....	.980	.640	.6242	57,300	26.0	43.5	.664	.630	.418	60,200	32.0
G 4.....	1.035	.630	.6520	52,100	26.5	36.0	.650	.638	.414	64,000	27.5
C 7.....	1.055	.660	.6963	57,300	27.5	51.0	.650	.663	.416	64,000	25.5
G 8.....	1.015	.665	.6750	52,888	30.1	36.2	.622	.668	.415	64,000	31.0

* On a 1-inch length disposed equally about the plane of least area.

In a special report on the subject of annealing as carried out at the mills, the inspector at the Norway Steel and Iron Works shows conclusively that the effect of annealing is frequently the reverse of what is to be expected. Curves A, B, C, Plate XIX., are strain diagrams, each plotted from the mean of four test pieces for unannealed boiler plate from three heats. The results are analyzed in Table XXXVII., showing excellent quality, while the curves give evidence of comparative homogeneity of the metal. From the middle of a plate of each of heats 274, 275, and 276, 8 test pieces were taken, four of which were subjected to the usual process of annealing by placing them in the annealing furnace with plates being annealed, and afterwards on the bed floor of the foundry to cool, observing the same course of treatment as that to which boiler plates are ordinarily submitted. Curves D, E, F, Plate XX., are the strain diagrams for the unannealed material, each being plotted from the mean of four pieces. Curves D', E', F', are the strain diagrams for the corresponding annealed pieces. The results, as arranged for comparison in Table XXXVII., show very unexpected changes. The tensile strength and elastic limit have been increased, the latter in a greater ratio, so that the elastic ratio is increased. The stretch is much diminished, the final area increased, and the uniform elongation along the length is probably much less. The work capacity, as measured by the strain curve, is very much diminished, so that the effect has not been one of simple hardening, but the intrinsic quality has been seriously lowered.

The inspector reports that of twenty-five other heats tested before and after annealing, nine-tenths showed an average of 5 per cent. increase in tensile strength with a decrease in elongation of 4 per cent. in 8 inches, and recommends that boiler plate be not so annealed.

TABLE XXXVII.—*Analysis of tests with strain diagrams accompanying Lieut. F. J. Drake's special report on annealing.*

Heat.	Condition.	Strain diagram.	Carbon.	Manganese.	Phosphorus.	Elastic limit per square inch.	Ultimate tensile strength per square inch.	Elastic ratio.	Stress at rupture per square inch of original area.	Final elongation.	Final area.	Area of strain diagram.	Work required to break a bar of 1 sq. inch sectional area and 8 inches long.	Ratio: Ult. T. S. × Elong'n.
			P. ct.	P. ct.	P. ct.	Lbs.	Lbs.	P. ct.	Lbs.	P. ct.	P. ct.	Lbs. p. c.	Ft. lbs.	P. ct.
392	Unannealed	A	.19	.37	.059	32,200	60,000	53.67	45,830	28.30	43.0	1,481,033	9,873	87.23
410	do	B	.13	.30	.060	34,000	61,800	55.02	46,250	27.70	41.0	1,508,855	10,059	88.15
487	do	C	.12	.43	.060	38,500	60,900	59.93	47,500	28.00	41.0	1,543,290	10,289	90.50
274	do	D	.14	.40	.057	30,600	60,060	50.95	47,900	30.25	44.0	1,618,450	10,756	89.09
275	Annealed	D'				34,100	62,970	54.15	53,800	25.75	50.0	1,452,350	9,682	89.58
275	Unannealed	E	.15	.31	.056	30,200	60,300	50.08	46,800	29.25	43.7	1,572,900	10,488	89.17
276	Annealed	E'				36,700	64,000	57.34	54,000	22.75	50.0	1,287,050	8,580	88.33
276	Unannealed	F	.15	.30	.060	35,000	61,000	57.38	50,800	28.00	44.2	1,595,133	10,555	92.70
282	Annealed	F'				39,200	62,120	63.11	51,900	23.00	48.0	1,277,850	8,519	89.44
282	Unannealed	G	.18	.61	.048	33,000	63,800	51.72	51,000	27.50	50.0	1,495,330	9,967	85.22
366	Annealed	G'				31,120	60,800	51.18	47,800	29.75	46.0	1,569,450	10,463	86.77
366	Unannealed	H	.21	.45	.050	35,000	64,320	54.42	52,000	26.60	48.0	1,458,430	9,923	86.99
455	Annealed	H'				32,300	61,000	52.95	48,900	28.30	47.0	1,519,200	10,128	88.01
455	Unannealed	I	.26	.40	.056	35,500	67,900	52.28	57,000	25.00	43.0	1,472,630	9,817	86.76
455	Annealed	I'				32,800	62,100	52.82	51,100	27.00	41.0	1,474,050	9,827	87.93

That these effects are due essentially to the method of annealing as there practiced appears from the following experiments: A sheet-iron cubic box was made, 2 feet on the side, with hanging door in one face and top perforated with half-inch drilled holes, to allow the escape of gases. From a plate of each of heats 282, 366, and 455, which were comparatively high in carbon and manganese, were cut two sets of triplicate test pieces having contiguous sides. One set of three pieces from each plate was heated in a small furnace to a very light cherry red and placed in the annealing box on a bed composed of equal parts of pulverized charcoal and lime and allowed to cool. The results arranged for comparison in Table XXXVII. are as ordinarily to be expected, and are very comparable to those of Table XXXIV. for the Chester and Black Diamond metals. The ultimate strength and elastic limit are diminished in about the same ratios, from 6 to 7 per cent., so that the elastic ratio is but slightly diminished;* the final elongation is increased 2.08 per cent. in 8 inches, while the final area is less by $2\frac{1}{2}$ per cent. of original area, so that the uniform elongation along the length is probably somewhat greater. The work capacity has been increased, showing improvement in intrinsic quality. Curves G, H, I, Plate XXI., for the unannealed, and G', H', I', for the annealed material, illustrate the changed behavior under stress.

The conclusion arrived at from a consideration of the results of annealing plates which have not been punched or otherwise worked so as to necessitate the removal of purely local strains is that the effect is as apt to be deleterious as beneficial, as the process is ordinarily carried out. Good metal shows little improvement in any case; and while inferior metal may be doctored up to show somewhat better test, the improve-

* A somewhat greater decrease in elastic ratio is to be expected.

ment in intrinsic quality is uncertain; but the fact that, as commonly done, annealing *may* continually and with reasonable certainty lower the working quality, and sometimes excessively so, should prevent any general resort to the practice for boiler- or other plate at the mills. It should also be remembered that each time a plate is heated and cooled without work upon it, it becomes more liable to damage from the next heat. Thus parts of flanged boiler plates may have been four times so heated before being worked in, if the plate was annealed before delivery.

Upon examining the different causes of the effects observed at the Norway and Chester works, the necessity of certain further precautions will appear. In the first place, the fuel should be comparatively free from ordinary impurities, and the flame should be kept neutral. The results will undoubtedly always be better if the furnace is so designed that the products of combustion are kept as much as possible out of contact with the material. While the heating up should be rather slow, the metal must not be soaked, and indeed should remain in the furnace the shortest time required to effect the desired results. Further, the temperature ordinarily applied is too high, and especially apt to be so locally. It need not be very much above the temperature of finishing at the rolls, and should never be above a medium cherry. It cannot be too carefully borne in mind that the temperature at which the original physical structure is destroyed and replaced by a coarser and weaker structure is considerably below bright yellow, and the metal should never be heated so high in annealing.

QUENCHING TESTS OF PIECES FROM DIFFERENT PARTS OF THE SAME INGOT AND OF SIMILAR PIECES DIFFERENTLY HEATED.

In consequence of the difficulty with the quenching test at the Norway works, in the early part of the inspection, certain tests were made by the inspector there as to the differences caused by taking the specimens from different parts of the plate with reference to original position of the ingot, and as to the effects of different methods of heating the pieces for test.

Pieces representing the upper and middle and lower end of the same ingots were taken for six heats and submitted to the quenching test with the following results. The pieces were all 2 inches wide and 10 or 12 inches long:

Quenching test.

[From upper end of ingot.]

No. of heat.	Thickness.	Behavior under test.
1	.562	Cracked nine-tenths of width on outer face, sides parallel.
2	.563	Cracked all across, sides parallel.
3	.563	Cracked one-third of width on outer face, ends touching.
4	.562	Broke suddenly at 35° opening.
5	.500	Cracked one-half inch on outer face at 90° opening.
6	.563	Satisfactory.

[From middle of ingot.]

1	.495	Commenced to crack at 50° opening.
2	.452	Satisfactory.
3	.516	Commenced to crack when requirement was reached.
4	.521	Cracked one-half inch on outer face, ends touching.
5	.515	Satisfactory.
6	.510	Broke at 60° opening.

Quenching test—Continued.

[From lower end of same ingots.]

No. of heat,	Thick-ness.	Behavior under test.
1	.497	Commenced to crack on both edges, ends touching.
2	.490	Satisfactory.
3	.500	Do.
4	.516	Do.
5	.520	Do.
6	.516	Cracked one-third of outer face, ends touching.

The difference in behavior due to position in the ingot is very marked, the upper ends giving very unsatisfactory results, while all the pieces from the lower end passed the test, except, perhaps, No. 6 heat.

The average tensile tests for the middle and lower thirds of the ingot were as follows :

No. of heat.	Ultimate strength.	Final elongation.
	<i>Pounds.</i>	<i>Per cent.</i>
1	61,259	26.12
2	61,667	27.12
3	58,699	26.50
4	58,277	26.00
5	60,067	26.00
6	63,150	19.00

Many plates being subsequently rejected on this test, additional experiments were made, including effect of different methods of heating. Pieces were taken from portions of plates representing what were originally the top, middle, and bottom of ingots from five heats of good quality—the tensile tests for four of these heats will be found in the table for Norway steel—and bent cold as finished, and after quenching from a cherry red, heated in a smith's fire with blast and in a still charcoal fire. Corresponding pieces were also cut from the slabs before rolling into plates (see p. 45) and submitted to quenching test with invariably satisfactory results.

<i>Cold-bending tests.</i> [From upper end of ingots.]				<i>Quenching tests.—Pieces heated with blast.</i> [From upper end of same ingots.]				<i>Quenching tests.—Pieces heated in Charcoal fire.</i> [From upper end of same ingots.]			
No. of heat.	Mark.	Behavior under test.		No. of heat.	Mark.	Behavior under test.		No. of heat.	Mark.	Behavior under test.	
1974	17 u 2	Cracked for $\frac{1}{2}$ inch on outer face, ends touching; granular fracture.		1974	17 u 2	Cracked entire width on outer face, ends touching.		1974	17 u 2	Cracked for $\frac{1}{2}$ inch at 90°; hard.	
1993	19 u 2	Satisfactory.		1993	19 u 2	Cracked $\frac{1}{2}$ inch on outer face, sides parallel.		1993	19 u 2	Cracked 2 inches, sides parallel; brittle.	
1995	20 u 2	Do.		1995	20 u 2	Satisfactory.		1995	20 u 2	Satisfactory.	
2009	21 u 2	Do.		2009	21 u 2	Do.		2009	21 u 2	Do.	
2013	22 u 2	Cracked for $\frac{1}{2}$ inch on outer face, ends touching.		2013	22 u 2	Commenced to crack, ends touching.		2013	22 u 2	Commenced to crack at 95° opening.	
[From lower end of same ingots.]				[From lower end of same ingots.]				[From lower end of same ingots.]			
1974	17 u 2	Cliffs in three places, ends touching.		1974	17 u 2	Broke at 130° opening; brittle.		1974	17 u 2	Cracked $\frac{1}{2}$ inches at 80° opening; hard.	
1993	19 u 2	Satisfactory.		1993	19 u 2	Cracked entire width, sides parallel.		1993	19 u 2	Broke at 40° opening; brittle.	
1995	20 u 2	Do.		1995	20 u 2	Satisfactory.		1995	20 u 2	Satisfactory.	
2009	21 u 2	Do.		2009	21 u 2	Do.		2009	21 u 2	Do.	
2013	22 u 2	Cracked for $\frac{1}{2}$ inch on outer face, ends touching.		2013	22 u 2	Broke at 125° opening; hard.		2013	22 u 2	Broke at 35° opening; hard.	
[From middle of same ingots.]				[From middle of same ingots.]				[From middle of same ingots.]			
1974	17 u 2	Cracked for $\frac{1}{2}$ inch on one edge, ends touching.		1974	17 u 2	Cracked $\frac{1}{2}$ inch on outer face, ends touching.		1974	17 u 2	Cracked for $\frac{1}{2}$ inch at 80° opening; hard.	
1993	19 u 2	Do.		1993	19 u 2	Cracked $\frac{1}{2}$ inch on outer face, ends touching.		1993	19 u 2	Cracked for $\frac{1}{2}$ inch at 90° opening; hard.	
1995	20 u 2	Satisfactory.		1995	20 u 2	Satisfactory.		1995	20 u 2	Satisfactory.	
2009	21 u 2	Do.		2009	21 u 2	Do.		2009	21 u 2	Do.	
2013	22 u 2	Do.		2013	22 u 2	Broke at 55° opening; hard.		2013	22 u 2	Broke at 10° opening; brittle.	

It appears that 2 heats, 1995 and 2009, gave invariably satisfactory results from all parts of the ingot, and however heated. The cold tests place the other three heats in the order of excellence 1993, 2013, 1974.

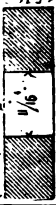
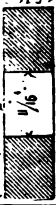


The pieces being heated with blast and quenched, their order of excellence is 1993, 1974, 2013, with little difference between the last two. The pieces being heated in a still charcoal fire, their order of excellence is 1993, 2013, 1974. So that the order of excellence from each method of test is practically the same. But little difference appears due to difference in heating, the blast giving perhaps slightly better results than the charcoal fire.

As to position in the ingot, the cold-bending tests show no noticeable difference; in the quenching test with blast, the upper end gives the best results and the lower end the worst; in the quenching tests with charcoal fire, there is but little average difference. As the lower end of the ingot is generally expected to give the best results, the inspector concluded, on examining the heating furnace and method of heating, that the temperature at the back of the furnace was frequently too high and the flame too cutting. The attention of the heaters was called to this fact, and with increasing familiarity with the test, the difficulty soon disappeared.

EFFECTS OF PUNCHING.

A few tests were made at Chester on the effect of punching, with and without countersinking, the ship plate of heat 486, that used for the special tests with strain diagram, Plate XVI. The results, as shown in Table XXXVIII., show a reduction of strength of $14\frac{1}{2}$ per cent., due to ordinary punching of an $1\frac{1}{8}$ hole, only $4\frac{1}{2}$ per cent. if the hole be partially countersunk, as practiced at the ship-yard, and an increase of 2.12 per cent. for a $\frac{3}{8}$ hole countersunk through. The thickness in each case was .51 inch and the width over all 2 inches. The relative size of punch and die, and consequent spread of hole, is not known. These results are as generally to be expected, the loss of strength being perhaps rather less than usual.

TABLE XXXVIII.—Showing effect of punching, with and without countersinking, Chester steel plate.

Heat.	Treatment.	Original dimensions of test piece.	Effective dimensions of test piece.	Effective area.	Ultimate tensile strength.	Ductility in 8 inches.	Reduction of strength.	Cross section through center of hole (half size).	Remarks.
486	Unpunched plate, four tests.	.....	1.00 x .507	.5070	64,200	Per cent. 25.15	Per cent.		Carbon, .12 per cent.; manganese, .37 per cent.; for heat.
486	Punched, 1 1/4-inch hole.	2.00 x .510	1.313 x .510	.6898	55,000	.....	14.33		
486	Punched, 1 1/4-inch hole, and countersunk as at ship-yard.	2.00 x .510	.....	.6215	61,400	.....	4.36		Commenced to crack at part of hole not countersunk, at 56,200 pounds per square inch.
486	Punched, 7/8-inch hole, and countersunk through.	1.986 x .510	.....	.6163	65,560	.....	*2.12		Commenced to crack at small edge of hole, at 61,080 pounds per square inch.

* Increase.

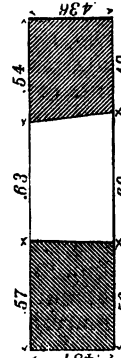
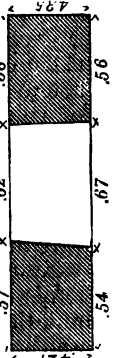
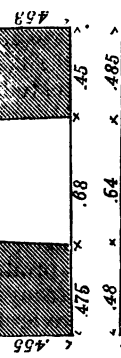
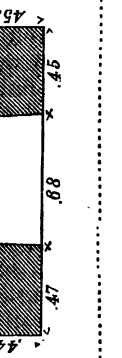

As is well known, the loss of strength from ordinary punching is due to the formation of a thin ring of highly strained metal forming the walls of the hole, of thickness depending on various circumstances, chief among which are the degree of hardness of the plate, its thickness, and the relative size of punch and die. The harder the steel, the thicker the plate, and the larger the die relatively to the punch,* the thicker is the overstrained ring of metal, and the greater the amount of subsequent riming or drilling necessary to remove it. M. Barba considered the removal of .04 inch of metal by cutting tool from a sheared edge or the walls of a punched hole sufficient to remove the bad effect in plates of ship or boiler quality not more than $\frac{1}{2}$ inch thick. An extension of the investigation with steel of harder quality, by Mr. A. F. Hill, C. E.,† develops the following results. Strips of plates, $\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$ inch thick of open hearth steels of .30, .40, and .50 per cent. carbon were punched with $\frac{3}{4}$ inch holes, and tested with various amounts of riming. Enlargement of diameter by .04 inch effected the restoration only of the $\frac{1}{4}$ inch and $\frac{3}{8}$ inch plates of .30 C., and of the $\frac{1}{4}$ inch plates of .40 C. Enlargement by .06 inch restored the $\frac{1}{4}$ inch plate of .30 C., the $\frac{3}{8}$ inch plate of .40 C., and the $\frac{1}{2}$ inch plate of .50 C. Enlargement by .08 inch restored the $\frac{1}{2}$ inch plate of .40 C. and the $\frac{3}{8}$ inch plate of .50 C., while the $\frac{1}{4}$ inch .50 C. plate required an enlargement of fully .1 inch.

The effect of a hole produced by a cutting tool in a steel plate is to increase the ultimate strength of the net section, and while the effect of punching is always to overstrain the adjacent material, yet if the damage to the material is equal to or less than the gain due to difference of distribution of the resisting area owing to the presence of the hole, no apparent loss of strength will ensue. Again, plates of the same thickness, giving almost identical results on tensile test, frequently show very different results on punching. Some unknown element of chemical quality or physical structure causes the difference. Plates, therefore, do not always show an apparent loss of strength due to punching. Table XXXIX. gives the results of testing some $\frac{7}{16}$ inch flats of Cambria steel from two comparatively hard heats, punched with $\frac{3}{4}$ inch holes not rimed. Careful measurements were made of the resisting areas, as shown on the sections, from which, also, it is seen that the average spread of the holes, owing to the clearance of the punch in the die, is about $\frac{1}{30}$ inch.

* While a relatively large die increases the thickness of the overstrained ring, and consequently the amount of riming necessary for its complete removal, the loss of strength due to such taper holes is less than with the proportions of punch and die commonly used.

† Vol. XI., Trans. Am. Inst. Mining Engineers.

TABLE XXXIX.—Showing effect of punching Cambria steel flat.

Heat.	Treatment.	Original dimensions of test piece.	Effective sectional area.	Apparent elastic limit.	Ultimate tensile strength.	Elastic ratio.	Ductility.	Reduction of strength.	Time of test.	Cross-section through center of hole, full size.	Remarks.
5565	Unpunched, 4 tests ...	In. 1.240 x .433	Sq. in. .5386	Lbs. 44,030	Lbs. 66,469	Per ct. 66.24	Per ct. +24.43	Per ct.	Min. 15		Carbon, 22 per cent.; manganese, .54 per cent. Fracture silky-plane. Somewhat laminated on one side. Opening of inner edge of hole 0.15 inch on each side.
5565	Punched, 4-inch hole ...	In. 1.738 x .436	.4714	49,872	66,334	75.18	15.5	.20	9½		Fracture silky-plane. Opening of inner edge of hole 0.12 inch on one side and 0.105 inch on the other.
5565	do	In. 1.773 x .428	.4816	53,011	64,118	82.68	15.0	3.54	8		Rise of elastic ratio, 12.66 per cent.
5565	Average punched .....	.....	.4765	51,442	65,226	78.90	15.25	1.87	8½		Carbon, 22 per cent.; manganese, .50 per cent.
5567	Unpunched, 4 tests ...	In. 1.243 x .449	.5580	41,576	65,475	63.50	+25.25	.....	15½		Fracture silky-plane. Opening of inner edge of hole 0.11 inch on each side.
5567	Punched, 4-inch hole ...	In. 1.607 x .454	.4299	49,314	65,270	75.56	14.63	.34	8		Fracture silky-plane on one side; irregular on the other. Opening of inner edge of hole 0.15 inch on one side and 0.11 inch on the other.
5567	do	In. 1.602 x .448	.4220	48,104	65,640	73.29	15.5	1.27	9½		Rise of elastic ratio, 10.92 per cent.
5567	Average punched .....	.....	.4260	48,709	65,455	74.42	15.07	n/l	8½	.....	Rise of elastic ratio, 11.79 per cent.
5567	Average, both heats punched.	.....	.....	.....	.....	.....	.....	.95	.....	.....	.....

* In 8 inches.

† In 4 inches.

‡ Increase.

Stresses were applied as usual in this inspection. The hole in each case commenced to elongate under a stress about the elastic limit of the unpunched metal, although the beam gave no indication of disproportionate extension until a considerably higher stress was applied; but the elevation of apparent elastic limit is believed to depend somewhat on the rapidity with which stress is applied, being less with more rapid application. The average rise of apparent elastic ratio is seen to be nearly 12 per cent., an increase of nearly one-fifth. The walls of the hole commenced to crack at a stress somewhat below the maximum, and fracture occurred slowly and by visible shear with silky plane surfaces. The difference of extension of the metal of the walls of the hole and at the edges is very noticeable, as seen in the column of remarks, making any measurement of reduced area of very uncertain value. The extension of the punched pieces is given for 4 inches, but is really confined to the metal immediately adjacent to the holes.

The average loss of tensile strength for one heat is *nil*, and for the other only 1.8 per cent., being then all in one piece. The average loss for both heats is only .95 per cent., or about 650 pounds.

A comparison of these results with those in Table XXXVIII. shows that while these flats were slightly thinner, they were also of slightly harder quality, but had received very much more mechanical work in the rolls. The proportion of net to original section is rather less in the Cambria pieces, giving the metal a slight advantage. But speaking broadly, this steel shows no reduction of strength due to punching, and its chief peculiarity is the very large amount of mechanical work which it has received, rendering a connection between the two qualities highly probable.

Few subjects stand more in need of exhaustive treatment than this of the effect of punching, and it may even fall within the province of the steel manufacturer, favorably situated for such work, to supply the solution as to the proper manufacture of metal to suffer the minimum of injury under ordinary conditions.

NEW SECTIONS.

In connection with the manufacture of material, certain new sections of deck beams and T rolled in steel are worthy of attention. Of the beam sections in general use in this country for iron, the large majority are deficient in width of flange, so much so that there is frequently not room enough to stow the rivets unless the very greatest care is exercised in punching and fitting. This small width of flange, together with the very round form of the bulb generally used in connection with it, makes the section deficient in lateral stiffness, one of the main causes of ultimate rupture; and this is also sometimes further aggravated by extreme thinness of web or stem, frequently such indeed that the beam cannot be straightened or cambered without fluting, very much diminishing its initial stiffness.

Again, the design of these sections has been based largely on the consideration that the ultimate resistance of wrought iron to compression is considerably less than to tension, the area of the flange being correspondingly increased over that of the bulb. But it would appear that the behavior of the metal under these strains within the elastic limit should control the design, as actual rupture of the section in the ship is not to be contemplated, being in all cases preceded by too great deflection, if the quality of the metal be good. Also, it is a significant

fact, that under the conditions of practice the capacity of iron and steel to stand repeated applications of the same stress within the elastic limit is greater for compression than for tension. Thus in riveted girders of wrought-iron, in which the flanges are proportioned so as to be theoretically of equal strength, fracture nevertheless almost invariably occurs on the tension side under repeated application of load.

For steel the elastic limit and behavior within it may be taken as practically the same for tension and compression, so that, from what has been said about repeated applications of stress, steel beams should generally have a greater area of bulb than of flange. This is not, however, practicable in any but the deeper beams.

In order to intelligently arrange the sizes and weights of beams in any case, beyond thumb-rule or the ordinary good practice, it is necessary to remember that, of whatever pattern, the rolls are always designed for a given weight, for which also the parts of the section are proportioned to what may appear to be the best advantage. If it be desired to make a heavier beam, the rolls are spread; if a lighter, they are screwed together. The distance apart of the rolls is generally considered to affect all parts of the section alike, within certain limits, or the increase of width of flange and bulb and of thickness of web will be identical.* On account of the greater length of web, however, the difference of weight will chiefly arise from the change of thickness of the web. Thus, if, for the weight to which the rolls are designed, the thickness of web is suitable for the transmission of stress from flange to bulb by its resistance to shearing and buckling, any increase of weight will diminish the efficiency of the beam per pound weight, inasmuch as the efficiency of the metal added to the web to resist transverse straining of the beam is only one-third of an equal addition to the flanges. It accordingly happens that a beam of given depth and weight from one manufacturer may have considerably less absolute strength and stiffness than a lighter beam, of the same depth but of different pattern, from another maker. Thus, unless the beams are to be made according to special pattern, which will rarely be the case, the exact weight per foot should be decided with reference to the design of the rolls. For instance, consider the 8-inch 27-pound beam (Table XL.) used amidships on certain decks of the Atlanta, Boston, and Chicago, in comparison with the 24½-pound beam of the same pattern used at the extremities of the same decks. The exact weight of the heavier beam in accordance with the actual section used for calculation is 27.3 pounds, that of the lighter 24.45 pounds, so that the heavier beam weighs 11.65 per cent. more than the lighter. The moments of resistance are respectively 16.52 and 15.90, or the heavier beam is only 3.9 per cent. stronger or stiffer, since the moment of resistance is a better measure of stiffness than of ultimate strength. The rolls were designed for 25 pounds, for which weight the parts are considered well proportioned, and it is seen that the increase of strength for increased weight is altogether disproportionate. The relative efficiency of the two sections may be seen from the last columns to be as .605 to .65, or the heavier beam is 6.9 per cent. less efficient than the lighter. This efficiency as gauged by the moment of resistance per pound weight per foot may be apparently much increased by rolling the section below the designed weight, but only at the expense of diminished ultimate

* The truth of this proposition will depend on the details of the roll passes, as the flanges may not fill the grooves in the last few passes, in which case practically no difference in width of flange will occur over a considerable range of weight.

strength of the section from lack of strength and stiffness of the web under heavy strains. Where stiffness alone is to be considered, this may generally be done with advantage, and indeed is contemplated in such reductions as above mentioned. But without inordinate expense, the manufacturer cannot make rolls to suit each individual case, unless the order be large, and it frequently happens, as shown, that the lighter beam may be practically as stiff and as strong as the heavier.

The foregoing considerations have been based upon the qualities of the beams unsupported by plating. When so supported, the maximum efficiency demands diminished flange area, larger fillets under the flange, thicker webs, and especially larger bulbs. The plating in fact virtually increases the flange area resisting compression, calling for corresponding increase on the tension side of the girder and in the connecting web. The beams supporting protective deck-plating should be designed with this in view, and such beams generally have an angle, or one-sided, flange. Such beams, as well as those subjected to violent and vibratory strains and generally supported by plating—at least over the parts most severely strained—are usually comparatively deep, so that the better to satisfy the average conditions the deeper beams should not have increased width and area of flange, but heavier webs and especially larger bulbs. Where the depth of beam is to be diminished from considerations of space, it may well happen that under plating some of the deeper rail patterns may be used to advantage, being at least, weight for weight, preferable to tees or double angles, while having sufficient flange area for connection to the plating.

As regards the pattern of steel beams, the flanges should not have more taper in thickness than is necessary for rolling, in order to increase the lateral stiffness. The metal of the bulb, on the other hand, is more efficient when concentrated, but by a flat pear-shaped bulb the virtual depth of the beam is increased, while connection with the pillars is more effective, and, as worked into carlings around mast-holes, &c., plating may be more readily secured by tap-rivets. Under the conditions of the metal in the web of a beam, it is probable that with steel of ordinary ship quality the thickness need be no greater than is common in well-designed iron beams. With steel of harder quality, the webs should be thicker; or it may be considered advisable in deep beams to increase the amount of reduction in the last pass (generally very small) and cut or stamp the rolls so as to leave vertical ribs in the web to increase the stiffness, where such projections will not interfere with the faying of the connecting pieces.

Plate XXII. shows the sections rolled under this inspection, illustrating some of the above remarks. Actual sections are shown except for the light 8-inch beam. Of the 7, 8, and 9 inch beams, the flanges are rolled for 5 inches, the bulbs are pear-shaped and perfectly flat on the under side, the webs terminate in deep fillets and are considered well proportioned for the weights for which the rolls were designed, viz. the 7-inch for 25 pounds, the 8-inch for 25 pounds, and the 9-inch for 28 pounds. The flanges have as little taper as was deemed safe in rolling, but this may be reduced with advantage. The 6-inch 16-pound beam was finished on rolls which had been used for iron. Considerably increased efficiency is apparent in the 18 pound 6-inch beam rolled especially for this order, but from trouble in the details of rolling the bulb-fillet on one side is misshapen. The size of the bulb of this beam may be increased with advantage.

Table XL. contains the chief properties of some of these sections, ac-

accompanied by those of iron beams of approximately the same weight as rolled at one of our most prominent mills. These are not given so much for comparison of efficiencies, because generally designed for much lighter weights, but to illustrate general features and clearly show the large differences which may arise between beams of the same weight of different patterns. The properties are as given in the manufacturer's hand-book. By the moment of resistance is meant the bending moment which will produce a stress of 1 pound per square inch on the extreme fiber.

TABLE XL.—*Properties of certain beam sections.*

Nominal size of beam.	Area of section.	Corresponding weight per foot.	Thickness of web.	Width of flange.	Width of bulb.	Neutral axis above bottom of bulb.	Moment of inertia about neutral axis.	Radius of gyration.	Moment of resistance.	Moment of resistance per pound weight per foot.
	<i>S. ins.</i>	<i>Lbs.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>	<i>Ins.</i>
9 inches by 5 inches by 31 pounds ¹	8.97	30.41	.563	5.08	2.12	4.93	99.90	3.34	20.26	.686
9 inches by 30 pounds ²	9.00	*30.51	.625	3.97	1.97	4.60	91.90	3.20	20.00	.655
8 inches by 5 inches by 27 pounds ³	8.05	27.30	.581	5.00	2.04	4.40	72.68	3.00	18.52	.605
8 inches by 27 pounds ⁴	8.10	*27.46	.712	3.96	1.71	4.49	61.60	2.78	13.75	.501
8 inches by 5 inches by 24½ pounds ⁵	7.21	24.45	.437	5.00	2.00	4.31	68.55	2.08	15.90	.650
8 inches by 24½ pounds ⁶	7.38	*25.02	.614	3.86	1.61	4.49	57.30	2.79	12.75	.509
7 inches by 5 inches by 25 pounds ⁷	7.12	24.14	.458	4.90	2.08	3.87	51.05	2.68	13.19	.546
7 inches by 23 pounds ⁸	6.90	*23.40	.625	3.75	1.75	3.98	43.00	2.50	10.89	.462
6 inches by 3½ inches by 16 pounds ⁹	4.82	16.34	.417	3.48	1.35	3.53	24.31	2.24	6.89	.422

* Weight if rolled in steel.

¹ Used for gun-deck beam, Chicago.

² Iron, as manufactured at Union Iron Mills.

³ Berth and spar decks, amidships, Chicago; berth and main decks, amidships, Boston and Atlanta.

⁴ Iron, as manufactured at Union Iron Mills.

⁵ Berth and spar decks, for'd and aft, Chicago; berth and main decks, for'd and aft, Boston and Atlanta.

⁶ Iron, as manufactured at Union Iron Mills.

⁷ Main-deck beam, Dolphin.

⁸ Iron, as manufactured at Union Iron Mills.

⁹ Berth-deck beam, Dolphin.

Plate XXII. shows the section of the 4½" by 3" tee used for bulkhead stiffeners and in other places on the larger vessels. The primary object of such a section in ship construction at the present time being to serve as an edge strip across the joint of bulkhead plates while the stem acts as a stiffener, the flange is made broad and of parallel thickness slightly in excess of ordinary bulkhead plating, while the stem or tongue is only as deep as the deep flange of angles used for stiffening purposes. The stem of a tee should have the least possible taper consistent with good rolling so as to throw the metal as far out as possible.

The open and close tests for deck beams and tees are illustrated by broken lines. In the tee, the stem may also be laid flat on one side of the flange.

PROPOSED SECTIONS.

There seems no reason why in future construction advantage should not be taken of some sections of great efficiency and lightness which have for some time been used in Europe. The more important of these is the 6-inch Z (Plate XXIII.) extensively used in the main framing, where only one thickness of plating is worked, and around magazines,

Plate ~~XXIII~~ III

I Bar

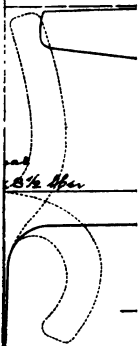
6' x 3½' x 3' x 15 lbs.

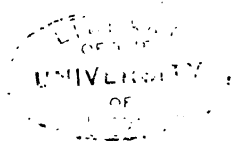
*Proposed Stem Sections
in Steel ~*

Angle Brigs

5' x 2½' x 11 lbs.

UNIVERSITY OF
MICHIGAN
LIBRARY





shaft alley and other important vertical bulkheads. This section of 15 pounds may be considered as replacing two angles back to back, 4 by 3 inches by 8 pounds, and 5 by 3 inches by 10 pounds, riveted through the lap. Although more difficult to bend than single angles, the saving in weight and in punching, fitting, and riveting, more than counterbalances this difference. In the present state of supply of ship material, competition not being particularly active for steel shapes, its cost at the mills should be very little more than the average. It is more easily rolled than the channel section and, in 1872, 6-inch Z bars with $2\frac{1}{2}$ -inch flanges were rolled in iron by the Phoenix Iron Company for certain bridge-builders. Other sizes of Z bar, in frequent use in Great Britain, are 10-inch by $3\frac{1}{2}$ -inch by $3\frac{1}{2}$ inch by 19.8 pounds and 5-inch by 3 inch by $2\frac{1}{2}$ -inch by 12 pounds, especially the former for longitudinal stringers, frames behind armor, &c.

Under light decks and platforms, especially where light plating is worked, a section more efficient as a stiffener and stronger than an angle is obtained in the angle bulb (Plate XXIII.), the size generally used being 5-inch by $2\frac{1}{2}$ -inch by 11 pounds. The bulb may be on either side of the web but is preferably on the same side as the flange. Another size of angle bulb, invariably used under armor-decks in the iron-clads of the British navy, is 9-inches by $3\frac{1}{2}$ -inches by 24 pounds.

CHEMICAL REQUIREMENTS.

For certain classes of steel, requirements limiting the amounts of certain chemical elements, notably carbon and phosphorus, have for some time been exacted. In steel rails, the carbon, phosphorus, silicon, and manganese have all been restricted at times, and now many mills work more or less closely to chemical formulæ. Some railroads place both higher and lower limits to carbon, and frequently a definite higher limit to phosphorus, an element always supposed below a certain extreme amount. The governing considerations are, in the order of importance, wear, brittleness, and stiffness, but the virtues of many of the particular formulæ proposed are purely fanciful. It has indeed not yet been decided which will wear best, so-called hard or soft rails, and opinion fluctuates as reports are received from the authorities of prominent railroads in this and other countries favoring one or the other general quality. In fact, while it is recognized that the conditions of traffic doubtless influence the best average quality, little has been done to give definition to current ideas. The most remarkable and elaborate work on this subject was done by Dr. C. B. Dudley, chemist to the Pennsylvania Railroad, and formed the subject of papers read before the American Institute of Mining Engineers in 1878 and 1881, and which provoked long and valuable discussion. It may be interesting to state that as the result of his investigations the following limiting chemical specifications were proposed as being best adapted for the conditions of traffic on the Pennsylvania Railroad:

Phosphorus, not above 0.10 per cent.; silicon, not above 0.04 per cent.; carbon, between 0.25 per cent. and 0.35 per cent., with an aim at 0.30 per cent.; manganese, between 0.30 per cent. and 0.40 per cent., with an aim at 0.35 per cent.; sulphur and copper, no specifications.

The difficulty and expense of carrying out on the material of rails a system of tests of representative value at all proportionate to those in use for structural steel, have driven consumers to specifications containing chemical requirements, which have, however, increased value in this case from the uniformity of treatment of rail metal subsequent

to tapping, arising from the large scale on which the manufacture is carried on and the precision and smoothness of working necessary in the face of active competition.*

But structural steel has also been occasionally subjected to chemical requirements. For "fire-box metal," or the parts of a boiler in contact with the flame, it has long been recognized that low phosphorus is highly desirable in steel as in iron. If the percentage of phosphorus be much above .05 per cent. in such material, internal strains appear to be produced under the ordinary conditions of working, causing rapid deterioration and sometimes sudden failures. Accordingly such material is generally purchased with explicit agreement or general understanding that this limit is observed.

Certain bridge engineers have of late undertaken to exact chemical requirements for bridge steel, and the specifications of the railroad bridge across the Ohio River at Henderson, Ky., extracts from which are given in Appendix, p. 211, *et seq.*, contain requirements for higher and lower limits of carbon for both tension and compression metal and the .10 per cent. limit for phosphorus, together with what are believed to be the most elaborate physical tests ever applied to structural material. Whatever opinion may be entertained as to the necessity of such requirements, or indeed of their propriety in the present state of our knowledge of the subject, they at least mark a tendency in the direction of chemical specifications, and the steel has been successfully made to them.

While the possibility of chemical specifications being relied upon for structural steel is very remote, yet, in originating requirements for material it becomes necessary, especially in connection with intended cost, to appreciate the margin allowed the manufacturer; and although, as we have seen, the physical qualities of steel are affected in many ways, some little understood, by treatment subsequent to tapping, yet, at any particular works, the methods and appliances in use, if not the best, cannot be altered without serious expenditure of time and money, so that for range of physical quality the manufacturer relies solely on the ingredients and proportions of the charge and subsequent treatment in the furnace. With this as the preliminary consideration, an analysis of the results of tensile tests on a chemical basis was undertaken. While, in order to avoid the region of debate, the Board confines itself to the most general discussion of the results, yet it will be readily understood that for even a general analysis of, and useful deduction from, a large number of tests as contained in lengthy tables, an amount of arithmetical labor is necessary such as to deter any but the most persistent investigator from the attempt, so that a summary upon any acceptable basis may well form a valuable addition to the itemized results.

But before proceeding to such a consideration of the results, it becomes necessary to examine the ground work in stating and considering the methods of chemical analysis commonly used in American steel works. While the differences arising are rarely comparable to those obtained from physical tests under different systems, they are yet considerable, and offer almost as much field for discussion, both as to the

* In general for this class of steel the number of points, or hundredths of 1 per cent., of carbon may be fairly used as the gauge of mere hardness or softness, with the restriction that the phosphorus, the other chief hardening agent, is within the Bessemer limit of 0.10 per cent. For such steel also the percentage of phosphorus is taken as an inverse measure of intrinsic quality, so much so that, as this element is not removed in the ordinary Bessemer process, pig-iron containing sufficient silicon for the blow, and not more than the above-mentioned amount of phosphorus, is termed Bessemer pig, and forms a separate class in the trade.

most suitable methods and the results of any one method in the hands of different individuals. Considerations of expense largely control the choice of method and, to a certain extent, the manipulation under the method chosen.

METHODS OF CHEMICAL ANALYSIS USED IN AMERICAN STEEL WORKS.

A complete analysis commonly consists of determinations of combined carbon, phosphorus, manganese, sulphur, and silicon, although sometimes extended to include graphitic or dissolved carbon, copper, nickel, and cobalt. The amount of chemical analysis made on each heat or blow of steel depends very much upon the experience of the melters, the variety of product, the degree of knowledge of the ingredients of the charge, and finally upon individual practice. But few of the above determinations are ever made except in particular cases, and much steel is not sampled for the chemist at all. A general knowledge of the ores, with a few special analyses, suffices, as a rule, for an estimate of such elements as copper, nickel, and cobalt, the variation of which is of no consequence if the maximum probable quantity present be not too great. Careful account is generally taken of the pig used directly or to be puddled, with respect to the elements commonly included in a complete analysis, and the scrap used, if its history is not known, is sampled as completely as deemed necessary. The ferro-manganese and spiegeleisen are bought on analysis for certain elements carefully determined and the average amount of the other principal elements is taken account of. Thus much chemical work is generally done to obtain a more or less accurate knowledge of the composition of the charge.

The open-hearth process effects practically the complete* elimination of manganese and silicon and the reduction of carbon to the desired extent; the necessary amount of manganese is subsequently added with a small increase of carbon and silicon. The other elements are generally not affected. The product is therefore tested almost invariably for carbon and frequently for manganese. When boiler metal is aimed at, the exact amount of phosphorus may also be determined.

The Bessemer process generally effects the complete* removal of silicon and manganese and, in this country, of carbon, the two latter elements being then added to the desired extent. A certain amount of silicon being necessary for the "blow," this element is generally determined for the pig used, though much may be told from its fracture. A specially large number of silicon determinations are made when the "direct" process is worked, the metal being taken fluid from the blast furnace to the converter, no mixing being possible. The same determinations are generally made for Bessemer as for open-hearth steels.

In the basic Bessemer, or Thomas-Gilchrist, process, phosphorus must be added to the number of elements removed, and becomes the subject of careful study in charge and product.

COMBINED CARBON.

Mr. J. Bludgett Britton's Modification of Eggertz's† method (*vid.* Jour. Franklin Institute, May, 1870), is in general use, almost every chemist

* By complete elimination or removal as here used is meant the reduction below certain very small quantities.

† Dr. Eggertz's original method is as follows: "Dissolve in the cold 1-10 gm. of steel in from 1½ to 5 cubic centimeters of nitric acid (1.2 sp. gr.); place in water bath at 80° C.; cool, and pour off solution; pour a few drops of nitric acid on the residue in

introducing individual peculiarities of manipulation. It consists of a comparison of colors of solutions, in nitric acid of definite strength, of the steels analyzed with those of standard steels or with derived solutions.

A solution of coffee or caramel in weak alcohol—or better, a mixture of the two, as the mixture does not change color so quickly as the single solution—is made of such strength that its color corresponds exactly with that of a solution of 1 gram of standard steel (combined carbon accurately determined by special method), in 15 cubic centimeters of nitric acid (1.2 specific gravity). A second standard steel is taken with about .10 per cent. more carbon and 15 cubic centimeters of its darker solution is diluted with weak alcohol until its color corresponds with that of the lower carbon steel, the exact amount of the alcohol used being noted. The intervening standards, generally 2 points, or .02 per cent., apart, are then made by diluting 15 cubic centimeters of the solution corresponding to the higher carbon steel with proportionate amounts of alcohol. Similarly standard solutions for the next range of 10 points, or .10 per cent., of carbon may be obtained. The solutions, in test tubes of exactly the same diameter and hermetically sealed, are placed in the order of color in a tube rack with a space between each pair for the insertion for comparison of the nitric acid solution of the steel to be analyzed. The lowest color in a rack much used for soft steels is frequently given by a piece of selected colored glass in distilled water. A piece of tracing paper, ground glass, or a porcelain plate is attached to the back of the rack for the better definition of the colors. When not in use, the rack should be kept in a dark place and should be tested for change of color at least once a month.

The estimation of the carbon in a number of samples is conducted as follows:

One gram of each steel, finely divided (preferably by drill or other cutting tool), is added gradually to 10 cubic centimeters of nitric acid (1.2 specific gravity) in a tube, 1 to 1½ inches diameter, surrounded with cold water. When solution is almost complete the tubes are placed in a water bath containing water at 80° C. and heated for one hour, cooled rapidly in cold water, and filtered through a filter paper 9 centimeters in diameter, not previously moistened, into tubes of the same diameter as in the standard rack. When the solutions have reached a fixed temperature the carbon is determined by a comparison of shades.

Absolute uniformity of manipulation is necessary with this method, especially with the very soft steels, which give a very light solution.

The exact strength of the acid used, its purity, the exact amount of acid used, the size of the drillings, the heat at which solution takes place, the rapidity of solution, the length of time the tubes stand before being placed in the hot-water bath, the exact temperature of the bath, any variations of that temperature, the length of time in the bath, the amount of evaporation, the temperature of filtration, the length of time between filtration and comparison of colors, the temperature of comparison, the exact size and thickness of the tubes used, with any variation of each, the light in which comparison is made, all affect the apparent amount of combined carbon present.

When the doubtful representative value of the sample for chemical test as generally taken with respect to the pieces subjected to physical test is considered, especially in view of the recently discovered prevalence of hard centers or fluming of the impurities to the top and center

the tube and heat carefully over a lamp until there is no further liberation of gas; cool and add to the former solution. The liquid is now diluted until its color corresponds exactly with the standard which is of such a strength that 1 c. c. represents .0001 gram. of carbon." This method is not so accurate as Mr. Britton's modification.

of the ingot, it is evident that averages of many tests are necessary for consistency of results for steel of any one manufacture, and accurate comparison of independent results for steel of different manufactures is very difficult if not impossible.

PHOSPHORUS.

To the chemist, as to the steel manufacturer and worker, this element has very treacherous qualities, and the greatest care is necessary for its accurate determination. Several methods are in use, of which the chief are, in the order of accuracy, the molybdate and magnesia method, with various modifications, the direct molybdate or yellow precipitate method, and the acetate or citric-acid method. The first two are the most commonly used.

Molybdate and magnesia method.—Dissolve 3 to 5 grams of steel in nitric acid (1.2 specific gravity), using about 15 cubic centimeters per gram of steel. When solution is complete, add 5 cubic centimeters of hydrochloric acid; evaporate to dryness and heat on the hot plate or sand bath until all the acid is driven off. The hydrochloric acid prevents the formation of basic salts. Dissolve in concentrated hydrochloric acid, using only a small amount, boil for a few minutes, and evaporate quite low. Evaporate twice with 30 cubic centimeters of nitric acid, taking care not to render the iron oxide insoluble in nitric acid; dilute, and filter from silica. The filtrates and washings, which need not exceed 150 cubic centimeters, are neutralized completely with ammonia and a slight excess added. The precipitate is dissolved with concentrated nitric acid and the solution brought to a reddish yellow color; add ammonium molybdate solution in large excess (20 cubic centimeters per gram of steel), heat the beaker for fifteen to twenty minutes at 80° C., allow to stand at about 50° C. from an hour to an hour and a half, until the yellow precipitate has entirely settled to the bottom, and filter. Thoroughly wash the precipitate with an acid solution of ammonium nitrate—made of 325 cubic centimeters of nitric acid (1.2 specific gravity), 100 cubic centimeters ammonia (0.96 specific gravity), and 100 water—and dissolve with dilute ammonia on the filter; acidify with hydrochloric acid, and add ammonia to the very slightest perceptible excess. Heat the solution on the steam bath until all odor of ammonia is removed and a slight flocculent precipitate has separated; filter, add ammonia to the filtrate, and precipitate with magnesia mixture, stirring briskly for several minutes.

The flocculent precipitate (often spoken of by mistake as silica) sometimes contains a trace of phosphorus, which can be regained by dissolving in warm nitric acid, precipitating with molybdate solution, and, after fifteen or twenty minutes, filtering off the precipitate, which is then dissolved in ammonia and added to the main solution.

If the final precipitation is to take place rapidly, the solution should not exceed 30 cubic centimeters. As soon as the liquid above the precipitate is perfectly clear, it may be filtered. In this case, as with the yellow precipitate, clear liquid indicates complete precipitation. Now filter through a 7-centimeter paper, and wash with a solution of 1 part alcohol, 1 part ammonia (0.96 specific gravity), and 2 parts water, by bulk; transfer to a crucible, wet, and turn on the full heat of a Bunsen burner until the paper begins to char, when the flame is turned low and the carbon burned off at a dull red heat.

Weigh the precipitate as pyrophosphate of magnesia as soon as cold. (See Vol. X., Trans. Am. Inst. Mining Engrs., p. 330.)

Another way of working the molybdate and magnesia method, used in several steel works, is as follows:

Dissolve the steel in nitric acid; evaporate to dryness and heat in an air bath at 120° C. for several hours; dissolve in hydrochloric acid; filter; expel hydrochloric with nitric acid; precipitate in small bulk, made nearly neutral by ammonia, with ammonium molybdate solution; filter, and wash with acid ammonium nitrate; dissolve with ammonia; precipitate with magnesia mixture; filter and wash with ammonia-alcohol or dilute ammonia; ignite and weigh as pyrophosphate. (*Ibid.*, p. 323.)

Either of these two methods give accurate results if ordinary care is used in the manipulation. The points to be watched are to have the solution free from hydrochloric acid or chlorides and to have only enough free nitric acid present to keep the iron oxide in solution when precipitating with ammonium molybdate solution. The presence of

a large excess of ammonium nitrate hastens the complete separation of the yellow precipitate, and, to a certain extent, neutralizes the deleterious effect of chlorides. The first method requires from twelve to thirty hours; the second, forty-eight to seventy-two, with no greater accuracy.

A modification of the molybdate and magnesia method used at, at least, one steel works is as follows:

Dissolve in nitric acid; evaporate to dryness and render silica insoluble on sand bath; take up in hydrochloric acid; evaporate low and add ammonia in excess. Dissolve precipitate formed in concentrated nitric acid and filter from silica; precipitate with molybdate solution; filter, and wash with dilute molybdate solution; dissolve with ammonia; precipitate with magnesia mixture, and let stand two to three hours; filter and redissolve precipitate with hydrochloric acid (1 in 2); add citric acid; neutralize with strong ammonia, adding one-third volume in excess, and let stand four hours or more; filter, and wash with dilute ammonia; ignite, and weigh. The results are too low and entirely untrustworthy. (See Vol. X., Trans. Am. Inst. Mining Engrs., p. 203.)

Yellow precipitate method.—The Eggertz direct, commonly called the yellow precipitate, method is used in many steel works from the rapidity with which it can be worked. The results are not generally accurate unless all the conditions of manipulation are carefully systematized. The method is as follows:

Dissolve 1 gram of steel in nitric acid, evaporate to dryness, and heat on a hot plate or sand bath until free from acid; take up in concentrated hydrochloric acid, and evaporate low; add 5 cubic centimeters of nitric acid, dilute slightly, and filter from silica; evaporate solution to 20 cubic centimeters, add 20 cubic centimeters of molybdate solution, and stir. Heat to about 40° C. until precipitation is complete, and filter through weighed or counterbalanced filter papers; wash precipitate with water containing 1 per cent. of nitric acid until a drop of the filtrate leaves only a slight ring on being evaporated to dryness on a watch glass. Dry at 110° C. until a slight stain appears on the filter paper. One and sixty-three hundredths per cent. of the weight of the precipitate is calculated as phosphorus. (Chemical News, Vol. VIII., p. 254.)

The Brushing method (Trans. Am. Inst. Mining Engrs., Vol. X., p. 167) is the same as the above except that a larger quantity of steel is used and as much as possible of the dried precipitate is brushed from the filter paper and weighed on a watch glass, the remainder adhering to the filter paper being considered unworthy of attention. This method is in use, though no chemist taking pride in his work would introduce mechanical defects into chemical methods.

The yellow precipitate method as described gives low results on account of the incomplete precipitation of phosphorus in presence of hydrochloric acid, the error increasing with the amount of phosphorus. If the phosphorus is low—below .07 per cent.—fairly accurate results may be obtained by twice washing the precipitate with nitric acid to remove the hydrochloric, keeping the amount of free nitric acid down to about 5 cubic centimeters. When the phosphorus is from .07 to .12 per cent., the analyses will then show too much phosphorus, the error being as great as .01 per cent. at the higher figure; and if .15 per cent. of phosphorus be present the error becomes .02 per cent. If, however, the amount of free nitric acid present be increased to 10 cubic centimeters, the analyses will show too low. It would thus appear that when the approximate amount of phosphorus is known, reasonably accurate results may be obtained by varying the manipulation. But the general question is in dispute.

The causes of variation in results by this method are the amount of nitric acid present, the amount of iron per cubic centimeter, the temperature of precipitation, the strength of the molybdate solution, the amount of hydrochloric acid, and the impossibility of freeing the pre-

precipitate from adhering impurities by washing with water containing 1 per cent. of nitric acid.

In comparing the molybdate and magnesia and the yellow precipitate methods, the most striking difference is that, whereas in the molybdate and magnesia method 27.93 per cent. of the magnesium pyrophosphate weighed is phosphorus, in the yellow precipitate or direct method only 1.63 per cent. of the ammonium-molybdenum-phosphate is phosphorus, the apparent risk of error being therefore as 17 to 1 against the molybdate and magnesia method. But this is not the case, since the composition of magnesium-pyrophosphate is constant, while that of the ammonium-molybdenum-phosphate is variable, being affected by the amount of free nitric acid present as mentioned.

Citric acid or basic acetate method.—Though in use at few steel works, this method is employed by many commercial chemists. It is essentially as follows:

Dissolve 5 grams of steel in concentrated nitric acid to which a few drops of hydrochloric acid have been added; replace nitric completely with hydrochloric acid and filter from silica; dilute filtrate to 600 cubic centimeters, and add ammonia until a slight cloud forms; add 7 to 10 cubic centimeters concentrated ammonium sulphite, and boil until sulphurous acid is removed; cool by placing containing beaker in water, and add ammonia in just excess enough to produce a greenish precipitate. Add 40 cubic centimeters of acetic acid, and boil about 20 minutes; if the precipitate, after boiling 5 minutes, is very small or light-colored, add a few drops of ferric chloride and boil again. Filter the precipitate as hot as possible, and wash slightly with hot water. Dissolve in as little hot hydrochloric acid as possible, wash filter with a solution of 2 or 3 grams of citric acid in a little water, and complete washing with hot water. Evaporate filtrate and washings to 30 cubic centimeters, add excess of ammonia, cool, and add 6 to 8 cubic centimeters of magnesia mixture, stirring until the precipitate appears. Let stand in a cool place for 16 or 18 hours; filter, and wash slightly with dilute ammonia; dissolve with dilute hydrochloric acid on filter, wash with solution of $\frac{1}{4}$ to 1 gram of citric acid, and complete washing with hot water; cool, add ammonia, and cool again; add a few drops of magnesia mixture, stirring until the precipitate appears. Let stand 6 or 8 hours; filter, and wash with dilute ammonia; ignite and weigh as magnesium pyrophosphate.

The majority of chemists using this method obtain low results. The causes of error seem to be the incomplete precipitation of phosphorus as basic phosphate of iron and the well-known solubility of ammonium-magnesium-phosphate in citrate of ammonia.

MANGANESE.

The following method proposed by Mr. S. A. Ford (Trans. Am. Inst. Mining Engrs., Vol. IX., p. 397) is the most convenient and accurate for the determination of this element, and is much used:

Dissolve 1 gram of steel in concentrated nitric acid (1.4 specific gravity), bring to a violent boil, and throw in chlorate of potash until the yellow fumes cease; add a little more chlorate of potash, and boil a minute or two, filter through asbestos, and wash with hot concentrated nitric acid until free from iron. Dissolve the binoxide of manganese in hydrochloric acid, filter from asbestos, and wash with hot water; nearly neutralize with ammonia; add a very small quantity of acetate of soda and boil; filter, and wash lightly with hot water; redissolve the small quantity of oxide of iron in hydrochloric acid, again nearly neutralize with ammonia, and add a small crystal of acetate of soda; boil and filter. Unite the two filtrates, add an excess of phosphate of soda, then an excess of ammonia, and boil. When the precipitate is completely down and has assumed the silky appearance of ammonium-manganous phosphate, filter, wash with hot water, ignite, and weigh as manganous pyrophosphate.

It should be remarked that asbestos often contains magnesia and lime which are liable to contaminate the final precipitate.

A very convenient method for the determination of manganese believed to have been devised by Mr. Setterwald, of the Vulcan Steel

Works, Saint Louis, but published by Mr. Fred. H. Williams (Trans. Am. Inst. Mining Engrs., Vol. X., p. 100) is given as follows:

Prepare two standard solutions, the first a permanganate solution of such strength that 1 cubic centimeter is equivalent to 1 milligram of iron, and the second an oxalic acid solution such that 1 cubic centimeter is equivalent to 3 cubic centimeters of the permanganate solution.

Dissolve one or two grams of steel in concentrated nitric acid, and add chlorate of potash until the binoxide of manganese is completely precipitated; filter through asbestos, wash with hot water, and place precipitate and asbestos in a beaker; add a measured quantity of the standard oxalic acid solution slightly in excess of what the binoxide is capable of oxidizing; dilute to 60 cubic centimeters, add 3 or 4 cubic centimeters of concentrated sulphuric acid, heat to 70° or 80° C., and titrate with permanganate solution. Calculate the weight of iron equivalent to the oxalic acid oxidized by the binoxide, and the amount of manganese may be obtained from the proportion 112: 55:: weight of iron oxidized: x = weight of manganese. The method gives slightly low results, and may be improved by substituting a standard solution of ferrous sulphate for that of oxalic acid.

The Acetate Methods.—The two allied acetate methods are in very extensive use, viz., the ammonia and bromine, and the fixed alkali and bromine.

The ammonia and bromine method is as follows:

Dissolve in aqua regia or nitric acid, evaporate to dryness, and render silica insoluble; take up in hydrochloric acid, and filter; dilute to 1 liter, and neutralize with ammonia and carbonate of ammonia; add acetate of ammonia in excess, boil until the iron separates, and filter; redissolve in hydrochloric acid and repeat the separation as before. Cool the combined filtrates, and add bromine and strong ammonia. When the manganese oxide has separated, boil, filter, wash, dry, and weigh as Mn_2O_4 .

In the fixed alkali and bromine method, carbonate of soda replaces ammonia and carbonate of ammonia, and acetate of soda is used instead of acetate of ammonia; no strong base is added after addition of bromine.

Almost every chemist has his own modifications of these methods, the results obtained varying from very low, through accuracy, to very high, according to individual modifications and the skill of the manipulator. (See Trans. Am. Inst. Mining Engrs., Vol. X., pages 105-9, 173, 191, and 194.)

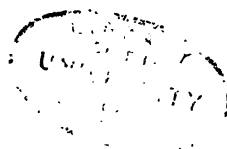
Volhard's manganese method is used to a limited extent. (Trans. Am. Inst. Mining Engrs., Vol. X., page 203.) It is as follows:

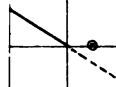
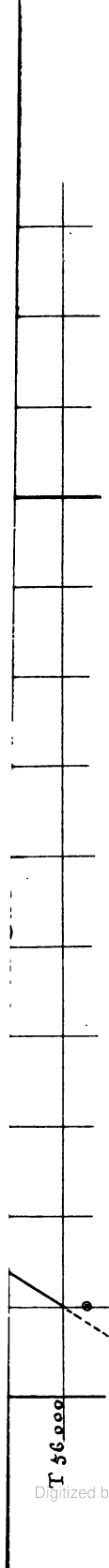
Dissolve 1.2 grams of steel in a porcelain dish with 25 cubic centimeters of a mixture of one part of concentrated sulphuric acid and four parts of nitric acid (1.2 specific gravity); boil down until fumes of sulphuric acid come off for two minutes, while carbonaceous matter is being destroyed. Dissolve in hot water, and wash into a flask graduated to hold 300 cubic centimeters; add zinc oxide, held in suspension in water, shaking the flask during the operation, cool, dilute with cold water to the mark, mix thoroughly, and filter. Pour off 200 cubic centimeters of the filtrate, representing .8 grams of steel, into a 500 cubic centimeter flask, add one drop of nitric acid (1.4 specific gravity), and titrate with permanganate. Then $\frac{1}{10}$ of the strength in iron equals the strength of the permanganate in terms of manganese. The method should give fairly accurate results with good manipulation for steels low in carbon.

SILICON.

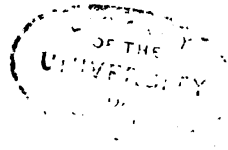
Dr. T. M. Drown's method is in general use. (Trans. Am. Inst. Mining Engrs., Vol. VII., page 437, and Vol. VIII., page 508). The determination is simple and rapid:

Dissolve in nitric acid (1.2 specific gravity), add excess of sulphuric acid, and evaporate until fumes of sulphuric acid are giving off. Dissolve the ferric sulphate in water, and filter off the silica, washing with hot water and hydrochloric acid until free from iron; ignite, and weigh as silica.

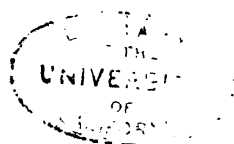




T 56.000



15	
30	
45	
60	



R	"	Ratio.
D	O	Final Elevation.

D O Final Elongation.

A. . " Shea.

$$E = \text{Modulus of Elasticity}$$

SULPHUR.

Dr. Drown's method (Trans. Am. Inst. Mining Engrs., Vol. II., page 224) is as follows:

Place 5 grams of steel in a 200 cubic centimeter flask and connect with a series of three absorption bottles containing permanganate of potash (1 gram in 200 cubic centimeters of water); add hydrochloric acid slowly to the steel (previously covered with water) so that not more than two bubbles of gas pass off per second. When the evolution of gas ceases in the cold, boil the solution in the flask for some minutes. Aspirate 500 cubic centimeters of air through the apparatus; fill the flask with hot water, and continue the aspiration until 1,500 cubic centimeters of air has been drawn through. Place the permanganate in a beaker, acidify with hydrochloric acid (if the permanganate contain silica or other impurities, evaporate to dryness and take up in hydrochloric acid), and precipitate with barium chloride in boiling solution. Weigh as barium sulphate.

Bromine in hydrochloric acid solution is used by many chemists instead of the permanganate, the manipulation being essentially the same.

Both methods give reliable results with careful manipulation, and they have almost entirely replaced the older methods of solution in nitro-hydrochloric acid with direct precipitation and absorption in an alkaline solution of silver or lead.

COPPER.

Occasional analysis is necessary for copper in steel of unknown manufacture or known to contain it in considerable quantity. Of the several methods in use, only two require mention:

(1) Dissolve 5 to 10 grams of steel in aqua regia; evaporate to dryness, and render silica insoluble; take up in a small quantity of hydrochloric acid, and reduce with excess of sulphurous acid; boil off the excess of sulphurous acid; dilute largely and pass sulphuretted hydrogen through the solution, at first in the cold, and finally at 60° C., to complete saturation. Filter, and dissolve the copper sulphide in nitric acid; replace the nitric acid with a few drops of concentrated sulphuric acid, and evaporate until fumes come off; dilute, and precipitate copper in a platinum dish by a weak battery.

(2) Dissolve 5 grams of steel in 10 cubic centimeters of concentrated sulphuric acid diluted with 100 cubic centimeters of water; add 2 cubic centimeters of a concentrated solution of thio sulphite of soda, stirring well; boil for 15 minutes and filter. Dissolve the sulphide of copper in aqua regia, and evaporate with 2 cubic centimeters of sulphuric acid until white fumes are given off; cool, dilute with water, and add an excess of ammonia; allow to settle; filter, and wash with water containing ammonia. Evaporate the excess of ammonia from the filtrate, acidify with sulphuric acid, and precipitate the copper with hyposulphite of soda; filter, wash with hot water, ignite, and weigh as oxide of copper. (Trans. Am. Inst. Mining Engrs., Vol. XI., page 300.)

OXIDE OF IRON.

This substance is one of the chief causes of general bad quality of steel; yet no method for its accurate determination has as yet been devised. Many of the failures of material after flanging at a heat or exposed to the flame in a boiler are ascribed to the presence of oxide of iron in considerable quantity, and with some plausibility, and under such circumstances its accurate determination would be of the greatest value. No matter how uniform the physical treatment of material, the self-sufficiency of chemical specifications can never obtain until oxide of iron can be accurately determined.

CURVES OF CARBON PROPERTIES.

Analysis of the results of tensile tests on the basis of increasing

amounts of carbon, as ordinarily determined for each heat, depends upon the existence of a sufficient number of tests and range of carbon to eliminate by average the effects of the other chemical elements and the accidents of manufacture and of test, while permitting the prominent features to be brought out. Many changes must be adopted in the method of chemical analysis and physical tests in ordinary use at steel works before anything like an adequate solution can be attempted. Thus a different and more satisfactory method of carbon determination for structural steel, or a suitable modification of the prevailing color test, is imperative; the adoption of a standard test piece is no less necessary; and, finally, the chemical determinations must be made, not from the little test ingot taken from the bath in the furnace, nor yet from the chip of a bloom during manufacture—though this is immensely preferable to the former—but from the actual plate or bar subjected to physical test, and, if possible, from a test piece itself. The necessity in well-ordered works of immediate chemical analysis by which to run the furnaces is by no means so urgent as formerly considered. Of the elements commonly analyzed for, carbon, manganese, and phosphorus, only the carbon can be rapidly determined, and the suitability of the metal to stand the physical requirements cannot be at all accurately measured by such individual analysis as is commonly made. The final disposition of the metal, if made subject to requirements, must await the results of the physical tests, and the connection between the ingredients and manipulation of the charge in the furnace and the physical qualities of the wrought metal cannot be examined until the physical tests are known.

These remarks apply to all special and structural steels made by any process. The system of most steel works in this respect is only suited to Bessemer rail, wire rod, or nail manufacture, or other loosely graded product, and needs radical change in the directions indicated if any reasonable certainty in the manufacture of high-grade special or structural steels is to be attained.

Of the steels manufactured under this inspection, the results of all chemical work done in connection with the Chester and Cambria steels have been kindly supplied by the manufacturers; the carbon and manganese of every heat of Norway steel were also readily supplied. Of the chemistry of the Black Diamond steel nothing is known, except as given in the general statement of the materials used in its manufacture. In the analysis of the Chester results, all the heats are not included, as complete chemical information had not been obtained when the curves for this steel were constructed. The chemistry of the Cambria steel is very incomplete, even the carbon not being determined for every heat. The great variety of product of these works limits the amount of chemical work for any one class of product, although collectively a great amount of chemical work is done and the laboratory is specially well equipped; further, after a few careful analyses for a given class of product, much chemical work is not thereafter deemed necessary. Heats rejected on a single test are not included in the table for this steel. Except for a few special heats, no phosphorus determinations were supplied for the Norway steel.

The pieces for chemical analysis of the Chester steel were test ingots taken from the furnace during tapping.* For the Norway steel, chips from the slabs as sent to the Bay State Works (see p. 44) were generally used. For the Cambria steel, chips from a bloom—generally 7 by 7

* A piece of the test plate is now used at these works.

inches—were taken. The methods of chemical analysis in use at each of the above works have been given in connection with the manufacture of the steels, but are again stated under each heading.

The results of test for each percentage of carbon being averaged as given in the first columns of the tables, the corresponding spots were set off on the diagram, each marked with its number of heats. To obtain the mean curve the spots were taken in groups of three consecutively, thus: C. 10, C. 11, and C. 12; C. 11, C. 12, and C. 13; &c., and each spot having the weight corresponding to the number of heats of that carbon, the center of gravity of each group was obtained, giving a series of first derived spots. If these spots are not sufficiently regular to pass a curve, the method is repeated, obtaining a series of second derived spots. In general this is not necessary and can only be done at the sacrifice of local features, the tendency being evidently to flatten the curve. The solid drawn portions of the curves are considered well defined by the derived spots; the dotted terminals are probable.

The last columns in the tables give the results obtained from the curves, and the summaries show the leading features. The average changes for a point of carbon are taken as far as possible between points in the same phase on the successive hummocks or wave-like portions of the curves.

Of the Chester and Norway steels the tensile strength, ductility, and final area are the only properties plotted. For the Cambria steel, the elastic limit, elastic ratio—as obtained from the curves of ultimate strength and elastic limit—and the modulus of elasticity are added. The latter is drawn as a straight line, the irregularity of the spots and small number of heats not producing a sufficiently definite curve. Much importance is not to be given to it.

TABLE XLI.—Drillings for analysis taken from small test ingot removed from the furnace while tapping.

CARBON PROPERTIES OF CHESTER STEEL.

(Chemical methods: For combined carbon, the color test, dissolving a standard each time; for manganese, by dissolving in acid protosulphate of iron the binoxide precipitated from nitric acid solution by chlorate of potash and treating with permanganate of potash; for phosphorus, the yellow precipitate method. Magnesia method occasionally used as a check.)

Number of heats.	Carbon.	Manganese.	Phosphorus.	Average original sectional area.	Tests.			Plotted curves.		
					Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Ultimate tensile strength per square inch.	Final elongation.	Final area.
	Per ct.	Per ct.	Per cent.	Sq. inches.	Lbs.	Per ct.	Per ct.	Lbs.	Per ct.	Per ct.
1.....	.10	.310	.....	.4586	62,050	24.62	50.05	.....	29.05	41.80
6.....	.11	.313	.0598 for 5	.4937	55,724	29.28	39.92	58,000	28.20	43.00
7.....	.12	.351	.0505 for 4	.6180	58,226	27.18	45.29	57,570	27.60	44.25
11.....	.18	.340	.0491 for 10	.5491	58,352	26.72	46.73	59,050	27.25	45.50
27.....	.14	.375	.0486 for 16	.5942	60,569	26.90	46.18	60,390	26.85	46.75
28.....	.15	.383	.0518 for 21	.5719	61,618	26.75	48.16	61,530	26.50	48.00
24.....	.16	.393	.0528 for 17	.5641	62,517	25.65	49.46	62,520	26.05	49.20
13.....	.17	.404	.0461 for 10	.5492	63,333	25.89	50.45	63,600	25.60	50.25
5.....	.18	.416	.0487 for 8	.5719	65,169	24.81	48.71	65,150	25.10	50.65
6.....	.19	.447	.0548 for 5	.5812	67,062	24.69	51.69	67,100	24.75	50.60
1*.....	.20	.410	.0390	.5169	59,000	29.27	41.85	.....	24.45	50.30
1.....	.21	.460	.....	.7036	74,535	24.30	50.50	.....	24.25	49.75
1.....	.22	.430	.....	.5584	66,075	23.74	48.00	.....	24.05	49.00

* Omitted as beyond the limits of error.

SUMMARY.

Number of heats (omitting .20 carbon).....	180	
Average manganese.....	.3813	per cent.
Average phosphorus.....	.0511	per cent. for 91 heats.
Average original sectional area.....	.5702	square inch.
Average increase of tensile strength per .01 per cent. carbon.....	1,387.5	pounds.
Average decrease of final elongation per .01 per cent. carbon.....	.425	per cent.
Average increase of final area per .01 per cent. carbon.....	.600	per cent.

TABLE XLII.—*Drillings for analysis generally taken from slab 21 inches wide by 4 inches to 7 inches thick.*

CARBON PROPERTIES OF NORWAY STEEL.

[Chemical methods: For combined carbon, the color test; for manganese, a special volumetric process, checked occasionally by the nitric acid and chlorate of potash method.]

Number of heats.	Carbon.	Manganese.	Tests.			Plotted curves.		
			Average ultimate tensile strength per square inch.	Average final elongation.	Average final area.	Ultimate tensile strength per square inch.	Final elongation.	Final area.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Per cent.</i>	<i>Per cent.</i>
3.....	.11	.363	59,110	26.75	50.00	59,500	26.25	47.40
29.....	.12	.377	60,703	25.68	47.35	60,600	25.65	48.80
33.....	.13	.355	61,460	25.27	49.40	61,300	25.50	49.50
36.....	.14	.351	61,514	25.33	49.31	61,620	25.65	49.00
58.....	.15	.339	61,863	25.63	48.03	61,760	25.85	48.79
31.....	.16	.394	61,866	26.09	48.61	61,890	26.00	48.80
31.....	.17	.381	62,061	25.51	43.53	62,110	25.80	49.35
66.....	.18	.380	62,343	25.49	48.92	62,670	25.50	49.10
40.....	.19	.423	63,349	25.08	47.58	63,150	25.20	48.00
15.....	.20	.425	63,672	24.92	47.40	63,700	24.80	47.60
10.....	.21	.421	65,660	24.67	49.35	64,030	24.70	48.40
11.....	.22	.363	63,263	24.61	49.00	64,160	24.75	49.50
7.....	.23	.397	64,026	25.57	50.00	64,280	25.20	49.30
1.....	.24	.440	62,253	28.00	44.00	64,460	25.50	48.30
1.....	.26	.400	66,839	25.00	43.00	65,520	25.35	48.30
1.....	.27	.470	70,532	24.00	49.00	66,200	24.90	49.25
1.....	.31	.390	72,754	25.00	62.00	67,800	25.25	52.50

SUMMARY.

Number of heats.....	369
Average manganese.....	3778 per cent.
Average phosphorus (believed to be) not above.....	.06
Average increase of tensile strength per .01 per cent. carbon.....	419 pounds.
Average decrease of final elongation per .01 per cent. carbon.....	.078 per cent.
Average increase of final area per .01 per cent. carbon.....	.116 per cent.

TABLE XLIII.—*Drillings for analysis generally taken from 7" by 7" bloom.*

CARBON PROPERTIES OF CAMBRIA STEEL.

[Chemical methods: For combined carbon, the color test; for manganese, the acetate of soda and bromine process; for phosphorus, the molybdate of ammonia and yellow precipitate method.]

Number of heats.	Carbon.		Average original sec.		Results of tests.						Results from plotted curves.					
	Per ct.	Sq. in.	Lbs.	Average elastic limit.	Average ultimate tensile strength.	Average elastic ratio.	Average final elongation.	Per ct.	Average final area.	Average modulus of elasticity.	Elastic limit.	Ultimate tensile strength.	Elastic ratio.	Final elongation.	Final area.	Modulus of elasticity.
1.....	.09	.5281	37,638	58,920	62.87	27.05	50.88	49.25	Lbs.	Lbs.	Lbs.	Lbs.	Per ct.	Per ct.	Per ct.	Lbs.
2.....	.11	.5584	41,450	61,544	67.35	25.98	50.88	49.25	27,930,000 for 1	38,450	58,300	65.95	28.85	51.00	51.00	27,480,000
6.....	.12	.5800	38,603	61,303	64.60	25.98	52.12	47.73	27,850,000 for 1	38,835	58,270	65.53	28.65	51.00	51.00	27,480,000
4.....	.13	.5886	40,222	61,386	65.50	24.76	47.73	47.73	25,920,000 for 1	38,630	61,200	63.10	28.45	51.00	51.00	27,500,000
24.....	.14	.5781	40,391	63,023	64.09	23.75	53.11	53.11	27,920,000 for 14	40,060	62,900	64.52	23.56	51.35	51.35	27,520,000
19.....	.15	.5476	41,942	63,016	65.80	23.24	51.59	51.59	27,092,000 for 9	40,500	62,900	64.39	23.70	52.25	52.25	27,530,000
22.....	.16	.5669	41,282	64,323	63.98	25.15	53.11	53.11	27,866,000 for 5	41,400	64,200	64.49	23.85	52.80	52.80	27,560,000
12.....	.17	.5693	41,318	63,915	64.64	25.39	53.50	53.50	28,394,000 for 5	41,800	64,700	64.70	23.20	53.30	53.30	27,560,000
13.....	.18	.5450	42,825	66,013	65.18	24.40	54.88	54.88	28,730,000 for 4	42,330	65,180	64.95	23.00	53.75	53.75	27,570,000
4.....	.19	.5410	42,630	63,475	67.19	26.03	53.95	53.95	28,540,000 for 2	42,800	65,050	65.20	24.80	54.10	54.10	27,580,000
8.....	.20	.5543	42,850	66,461	64.47	24.53	54.82	54.82	27,223,000 for 3	43,270	66,150	65.42	24.75	54.30	54.30	27,580,000
2.....	.21	.5396	45,541	67,847	67.02	24.13	52.16	52.16	28,340,000	43,770	66,600	65.72	24.75	54.30	54.30	27,600,000
1*.....	.22	.5540	39,090	63,220	61.53	24.83	56.77	56.77	28,700,000	44,250	67,100	63.95	24.70	54.00	54.00	27,610,000
2.....	.23	.5576	44,174	67,930	65.03	25.32	54.47	54.47	28,700,000	44,750	67,600	66.20	24.75	54.00	54.00	27,620,000
1.....	.24	.5396	42,210	66,125	63.84	24.35	51.67	51.67	28,140,000	45,250	68,125	66.43	24.80	53.80	53.80	27,630,000

* Omitted as beyond the limits of error. Subsequent analysis of a test piece gave .14 C.

SUMMARY.

Number of heats.....	120
Average manganese (believed to be) about.....	.450 per cent.
Average phosphorus (believed to be) about.....	.085 per cent.
Average original sectional area.....	.5577 square inch.
Average increase of elastic limit per .01 per cent. carbon.....	.453 pounds.
Average increase of tensile strength per .01 per cent. carbon.....	.655 pounds.
Average decrease of final elongation per .01 per cent. carbon.....	.138 per cent.
Average increase of final area per .01 per cent. carbon.....	.187 per cent.

The average steepness of the curves of tensile strength is very different, being especially great for the Chester steel. Other things being equal, the less mechanical work to which the material of the chemical sample has been subjected the steeper the curves should be, the effect of work of reduction being to increase the combined carbon, as shown by color tests,* but the conditions are so variable that this effect has never been quantified. Again, the condition of the metal in the little test ingot as used at Chester is not the same as in the plate ingots, cast and cooled under very different circumstances. Some idea of this effect may be obtained by considering the tensile strengths which would correspond to complete absence of carbon in each of the three steels. Carbonless Cambria steel, the other elements remaining the same, should have a tensile strength of about 53,250 pounds, with a possible error of about 1,000 pounds. The Norway steel should give about 55,750 pounds, with a possible error of about 750 pounds. The Chester steel would give the extremely low value of about 40,500 pounds, with a possible error of about 500 pounds. It is therefore probable that the Chester curve loses its steepness rapidly below .10 per cent. carbon.

The steepness of the curves would further appear to be influenced by the amounts of other elements present. Thus the Cambria and Norway steels had both been worked a good deal when the piece for chemical test was removed, the Cambria having received the most work, as it had also in the pieces tested. Yet the difference in steepness is sufficiently great to render it probable that the higher phosphorus and, perhaps, manganese of the Cambria steel have increased the rate of increase of strength per point of carbon.

It will also be observed that in the Chester steel, as well as, more imperfectly, in the Norway steel, increasing carbon is accompanied by increasing manganese, due probably to diminished oxidation in the furnace.

As possibly affecting the general character of the curves, the average sectional area was obtained for the Chester and Cambria steels. As has been shown (Plate VIII.), the apparent tensile strength of the Chester steel may be influenced by the proportions of the test piece, even with an 8-inch length. This effect seems to hold good in the curve for this steel, in which it will be noticed that the effect of correcting for difference of sectional area from the average value would be to bring the spots nearer the mean curve. No such result appears to hold for the Cambria steel.

For all the steels, the sinuous nature of the curves for tensile strength, ductility, and final area is the most notable feature apart from the differences of average steepness. This is particularly remarkable in the Norway steel. The humps and hollows agree very well in the various curves for the same steel. Thus a hump in tensile strength lies under a corresponding hump in final area and under a hollow in elongation. In other words, the intrinsic quality, as measured by efficiency number, has undergone a more gradual change with change of carbon than any single property. And in each steel this property will be found to have increased with increasing carbon, pointing to the advisability of using higher carbon metal as far as improving workmanship will permit.

The curves of Cambria steel are much increased in value by the curves of elastic limit and elastic ratio. Although the original spots for elastic limit appear somewhat irregular, the first derived spots lie

* Thus it is not uncommon for rail metal of about .40 carbon in the ingot to show 3 to 4 points higher in the bloom and 2 to 3 points higher yet in the finished section.

with almost perfect regularity on the curve drawn, itself the most regular of all the properties.

The derived curve of elastic ratio forms a very valuable basis from which to measure the physical condition of the metal as regards roll hardening from cold finishing, or rapid cooling after finishing, and possibly other disturbing causes. Under the average conditions of finishing, it is seen that for each carbon there is a corresponding value of elastic ratio, any departure from which measures the difference of physical condition from the average. Thus, if the elastic ratio be higher than corresponds to the observed tensile strength, it is strong evidence that the steel is intrinsically softer than as indicated by ultimate strength alone, and has been hardened in the rolls or in cooling. This effect may, however, be interfered with by comparatively small variations of other chemical elements besides carbon, notably phosphorus; and as illustrating the method by which these or similar curves obtained under more standard conditions may be employed for quantifying some of the conditions known to affect the physical tests of the metal, it may be as well to state the method of procedure in such a case.

In analyzing the results of physical test of a piece of steel of known chemical composition made and tested under standard conditions, it is first necessary to examine the elongation and final area for evidence of dirtiness or lamination in the piece—the fracture should also have been examined for evidences of lamination; if these two qualities are sufficiently near the average we may proceed, otherwise little useful result can be obtained. Departures from the average values of phosphorus and manganese are next examined, and it is here necessary to digress to note the nature of the effects produced by variations of these elements under ordinary circumstances.

As a hardener, phosphorus is generally considered to be even more effective than carbon, but its secondary effects are very different. Other things remaining the same, increase of phosphorus, besides raising the tensile strength, notably raises the elastic ratio, diminishes elongation, and more especially diminishes the reduction of area. Its effect in diminishing elongation, and probably also reduction of area, appears to be largely dependent on the amount of other elements present, especially of silicon. For convenience, the latter element must be supposed to vary little, and be present in quantity not above .04 per cent., as is common in open-hearth steels. The effect of phosphorus is then identical in nature to that of cold rolling or finishing, and is to be taken account of in much the same manner. Thus, in estimating the effect of departure from the normal elastic ratio, the influence of variations of phosphorus will have been taken account of. Further, high phosphorus metal is more influenced by cold rolling than steel with less of that element. Once quantified, under the condition of low silicon, the effect of a given absolute amount of phosphorus may probably be relied upon as practically constant.

Not so with the other most variable element, manganese. The basis from which the effect of variation is to be estimated is itself variable. To illustrate this, it is only necessary to make use of observed variations in the rolling quality of the metal, which is especially influenced by manganese. Thus, of two steels of precisely the same final composition with respect to carbon, phosphorus, manganese, and sulphur, but made from different stock, or in different ways, one may roll well and the other badly. What is sufficient manganese for one is insufficient for the other. This difference arises either from the different conditions in which the manganese may exist in the steel—the most prob-

able cause—or the variable amounts remaining of the oxide of iron whose hot-shortening effect the manganese counteracts. Under average conditions of any given method of manufacture, it is probable that a certain amount of manganese is necessary to prevent hot shortness, which may be called the *saturating* amount of manganese, while only the excess over this amount is free to influence the properties of strength and toughness. In different manufactures, the point of “saturation” of manganese will probably be different, while two heats of the same manufacture may be expected to vary from one another in this respect, depending on the stock and treatment in the furnace. The effect of excess of manganese above this point is certainly to increase the tensile strength, but its influence in other respects is not so decided.

To quantify the effects of phosphorus or manganese above or below the average amounts, we must have a few tests of steel varying only in the amount of one of these elements from the average, from which, by comparison with the carbon curve, a derived curve can be constructed for the effect of such variations.

The same method must be used to quantify the effect of departure from the normal elastic ratio previously corrected for variation of phosphorus.

By this method of comparison very fair results have been obtained from the Cambria curves, but the number of tests with special chemical determinations is too limited for perfect accuracy. Of these a few may be instanced. Thus,

(Piece 4503—1.)

Phosphorus	per cent..	.084
Manganese	do....	.488
Ultimate tensile strength	pounds..	69,230
Elastic limit	do....	50,000
Corresponding elastic ratio	per cent..	72.22
Final elongation	do....	20.00
Final area	do....	69.50

An inspection of these results shows, from the high elastic ratio, low ductility, and reduction of area, that the high tensile strength is due to cold finishing or other mechanical hardening, since the phosphorus and manganese are very near the average values. Careful determination of combined carbon in the test piece itself gave .14 per cent., for which the tensile strength should be 62,900 pounds, with a normal elastic ratio of 64.39 per cent. Thus the increase of elastic ratio to 72.22 per cent., or by 7.83 per cent., has raised the tensile strength 6,330 pounds. This increase of tensile strength with increase of elastic ratio is not probably at a uniform rate, but more rapidly as the elastic ratio rises.

Again,

(Piece 4875—1.)

Phosphorus	per cent..	.081
Manganese	do....	.208
Ultimate tensile strength	pounds..	55,400
Elastic limit	do....	33,210
Corresponding elastic ratio	per cent..	59.95
Final elongation	do....	28.60
Final area	do....	44.00

This steel shows low manganese and low elastic ratio, the latter probably corresponding to comparatively rapid and hot finishing. Accurate carbon determination of the test piece gave .10 per cent., for which the normal elastic ratio is 65.53 per cent. Estimating the effect of defect of

elastic ratio below normal value as somewhat less than that of excess, the difference of tensile strength corresponding to the defect of elastic ratio of 5.58 per cent. may be stated at about 3,000 pounds; or, under average conditions of finishing, the tensile strength would be about 58,400 pounds. As the tensile strength under these conditions, with average manganese, would be 59,270 pounds, the defect of .24 per cent. of manganese below the average of .45 per cent. diminished the tensile strength by not more than 870 pounds, provided none of the defect of elastic ratio is due to the low manganese. An equal excess of manganese above the average value has a much greater influence on the tensile strength, the *saturating* amount for this steel being believed to be near .40 per cent.

If we now consider the special tests of this steel taken from the deck-beam web, as given in Table XXXI.—the tests from the flat given in the same table have been mentioned as showing probable cold straightening or other treatment such that the elastic limit is not sufficiently marked—we have for the mean of the two pieces—*

Phosphorus .....	.080
Manganese (one piece) .....	.386
Ultimate tensile strength	pounds.. 63,017
Elastic ratio	61.18
Final elongation	26.00
Final area	55.16

This steel shows slight departure from average conditions in manganese, phosphorus, and elastic ratio. The defect of manganese of .064 per cent. may be credited with about 200 pounds tensile strength. The normal elastic ratio corresponding to the tensile strength so increased to 63,217 pounds is about 64.35 per cent. The defect, therefore, is to be taken as 3.17 per cent., probably affecting the tensile strength by about 1,000 pounds. So that bringing this steel up to the average conditions the tensile strength would be about 64,217 pounds, corresponding to .16 carbon. The carbon of one piece was .14 per cent. and of the other .16 per cent.

The above special cases have been considered only in order to clearly show the method of comparison. Many of the assumptions made, though formed on much more extended comparison, are still crude. Above all, the condition of the manganese is always uncertain, and something of the history of the stock and working in the furnace is necessary for any nice estimate of its effect. Nevertheless, the consistency of the physical and chemical condition of steel of this manufacture, tested as this was under fairly standard conditions, is truly surprising, and the method is highly suggestive of that which should be pursued in treating the results of steel of given manufacture tested physically and chemically under absolutely standard conditions, with special regard to the chemical determinations being made on the metal of the test piece itself. Under such circumstances alone can the complex influences affecting the behavior of a piece of steel be separately quantified and nicely balanced, and, from comparison of such results from steels of different manufacture, conclusions of the very highest interest may be also expected.

Combination or comparison of the curves obtained for the three steels is not possible with any accuracy, the conditions of physical treatment, manufacture, and carbon determinations being too widely different. It

* For particularly careful determinations of phosphorus and manganese in these and other pieces, the Board is much indebted to Mr. F. E. Bachman, chemist to the Phoenix Iron Company, and for specially determined carbons to Mr. T. T. Morrell, chemist to the Cambria Iron Company.

appears probable, however, that open-hearth mild steel of about .07 per cent. phosphorus, tested under the average conditions of this inspection, should show an average increase of tensile strength of not far from 650 pounds per square inch for an increase of .01 per cent. of carbon in the finished product with a simultaneous decrease of from .10 to .12 per cent. of final elongation in a piece of average dimensions, 60,000 pounds tensile strength and 27 per cent. elongation corresponding to about .10 per cent of carbon by color test in the test piece itself.* Large variations from these average results are to be expected from varying conditions of treatment and manufacture.

* It has long been known that the rate of increase of tensile strength itself increases with increasing carbon.

APPENDIX.

TESTS FOR PLATE, BEAM, ANGLE, BULB, AND BAR STEEL, USED IN BUILDING SHIPS FOR HER MAJESTY'S NAVY.

ADMIRALTY, November 3, 1880.

Strips cut lengthwise or crosswise to have an ultimate tensile strength of not less than 26, and not exceeding 30, tons per square inch of section, with an elongation of 20 per cent. in a length of 8 inches. The beam, angle, bulb, and bar steel to stand such forge tests, both hot and cold, as may be sufficient, in the opinion of the receiving officer, to prove soundness of material and fitness for the service.

Strips cut crosswise or lengthwise $1\frac{1}{4}$ inches wide, heated uniformly to a low cherry red and cooled in water at 80° Fah., must stand bending in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested.

The strips are all to be cut in a planing machine, and to have the sharp edges taken off.

The ductility of every plate, beam, angle, &c., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold under the hammer.

All steel to be free from lamination and injurious surface defects.

One plate, beam, or angle, &c., is to be taken for testing from every invoice, provided the number of plates, beams, or angles, &c., does not exceed fifty. If above that number, one for every additional fifty or portion of fifty. Steel may be received or rejected without a trial of every thickness on the invoice.

The pieces of plate, beam, or angle, &c., cut out for testing are to be of parallel width from end to end, or for at least 8 inches of length.

Plates will be ordered by weight per superficial foot: the weight named will always be the greatest that will be allowed for ship plates and for boiler plates under 4 feet in width; a latitude of 5 per cent. below this will be allowed for rolling in plates $\frac{1}{4}$ an inch in thickness and upwards and 10 per cent. in thinner plates. In plates for boilers over 4 feet wide and $\frac{1}{4}$ inch thick and upward a latitude of $2\frac{1}{4}$ per cent. above and $2\frac{1}{4}$ per cent. below will be allowed for the springing of the rolls, and 5 per cent. above and 5 per cent. below will be allowed in thinner plates over 4 feet wide. The average weight per foot of the plates ordered is to be ascertained by weighing not less than 10 tons at a time when larger parcels than 10 tons are delivered; if these 10 tons exceed the due weight (calculated as stated above), or are more than the beforementioned percentage below it, the whole may be rejected. In smaller deliveries than 10 tons the average is to be ascertained by weighing the whole parcel. The same conditions as to latitude and mode of ascertaining weight apply also to other descriptions of steel in the contract.

ADMIRALTY SPECIFICATIONS OF STEEL FOR BOILERS.

STEEL PLATES, BARS, RIVETS, &C.

The whole of the material used in boilers is to be obtained from steel makers whose names are to be submitted for approval. The steel is to be subject to the usual tests at the works of the manufacturer, under the supervision of the resident Admiralty overseer.

TESTS FOR STEEL PLATES, ANGLE, TEE, AND BAR STEEL.

The tests are as follows: Strips cut lengthwise or crosswise, to have an ultimate tensile strength of not less than 26 tons, and not exceeding 30 tons per square inch of

section, with an elongation of 20 per cent. in a length of 8 inches. The angle, tee, and bar steel and rivets to stand such forge tests, both hot and cold, as may be sufficient, in the opinion of the overseer, to prove soundness of material and fitness for the service intended.

Strips cut lengthwise or crosswise, $1\frac{1}{4}$ inches wide, heated uniformly to a low cherry-red, and cooled in water of 82° Fahr., must stand bending double in a press to a curve, of which the inner radius is one and a half times the thickness of the steel tested.

The strips are all to be cut in a planing machine, and to have the sharp edges taken off.

The ductility of every plate, angle, &c., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold by the hammer.

All steel is to be free from lamination and injurious surface defects.

The pieces of plate, angle, &c., cut out for testing are to be of parallel width from end to end, or for at least 8 inches of length.

STEEL FOR FURNACES. TESTS.

The furnaces and combustion chambers are to be made of steel of special soft quality. In addition to the above tests, these plates are to be tested by welding and forging, and some of the welded pieces are to be broken in the testing machine to ascertain the efficiency of the welding. The tensile strength of these plates must not exceed 25 tons per square inch.

STEEL CASTINGS. TESTS.

All steel castings for engines are to satisfy the following conditions: Tensile strength between 28 and 32 tons per square inch, with an extension in 8 inches of length of at least 10 per cent. Bars of the same metal $1\frac{1}{4}$ inches square should be capable of bending cold without fracture, through an angle of 90° , over a radius not greater than 2 inches. Test pieces are to be taken from each important casting.

ADMIRALTY INSTRUCTIONS FOR TREATMENT OF MILD STEEL.

(1) All plates or bars which can be bent cold are to be so treated; and if the whole length cannot be bent cold, heating is to be had recourse to over as little length as possible.

(2) In cases where plates or bars have to be heated, the greatest care should be taken to prevent any work being done upon the material after it has fallen to the dangerous limit of temperature known as a "blue heat"—say from 600° to 400° F. Should this limit be reached during working, the plates or bars should be reheated.

(3) Where plates or bars have been heated throughout for bending, flanging, &c., and the work has been completed at one heat, subsequent annealing is unnecessary.

(4) Where simple forge-work has been done, such as the formation of the joggles, corners, and easy curves or bends, on portions of plates or bars, and the material has not been much distressed, subsequent annealing is unnecessary.

(5) Plates or bars which have had a large amount of work put upon them while hot, and have had to be reheated, should be subsequently annealed. It is preferred that this annealing should be done simultaneously over the whole of each plate or bar when this can be done conveniently. If it is inconvenient to perform the operation of annealing at one time for the whole of a plate or bar, portions may be annealed separately, proper care being taken to prevent an abrupt termination of the line of heat. If the severe working has been limited to a comparatively small part of a plate or bar, annealing may be limited to the parts which have been heated, the same care being taken to prevent an abrupt termination of the line of heat.

(6) If desired, exceptionally long or quickly curved bars, such as frames, may be formed of shorter pieces, with the butts suitably shifted and strapped.

(7) In cases where any bar or plate shows signs of failure or fracture in working, the details of the cases should be forwarded to the admiralty, in order that instructions may be given as to the disposal of the bar or plate.

(8) It is not necessary to anneal plates or bars after punching, as a means of making good damage done in punching. For plating which forms an important feature in the general structural strength, such as the outer bottom plating, deck plating, deck stringers, &c., all butt straps shall have the holes drilled or be annealed after the holes are punched. In outer bottom plating, the holes, which are to be countersunk, should be punched about $\frac{1}{4}$ inch less in diameter than the rivets which are used, the enlargement of the holes being made in the countersinking, which should in all cases be carried through the whole thickness of the plates.

(9) Snap riveting is only to be employed for the internal work on transverse bulk-heads, floors, framing, and other subordinate parts of the structure, but on stringers, deck plating, and other parts subjected to considerable tensile strain countersunk riveting is to be used, and the holes treated similarly to those in the outside plating.

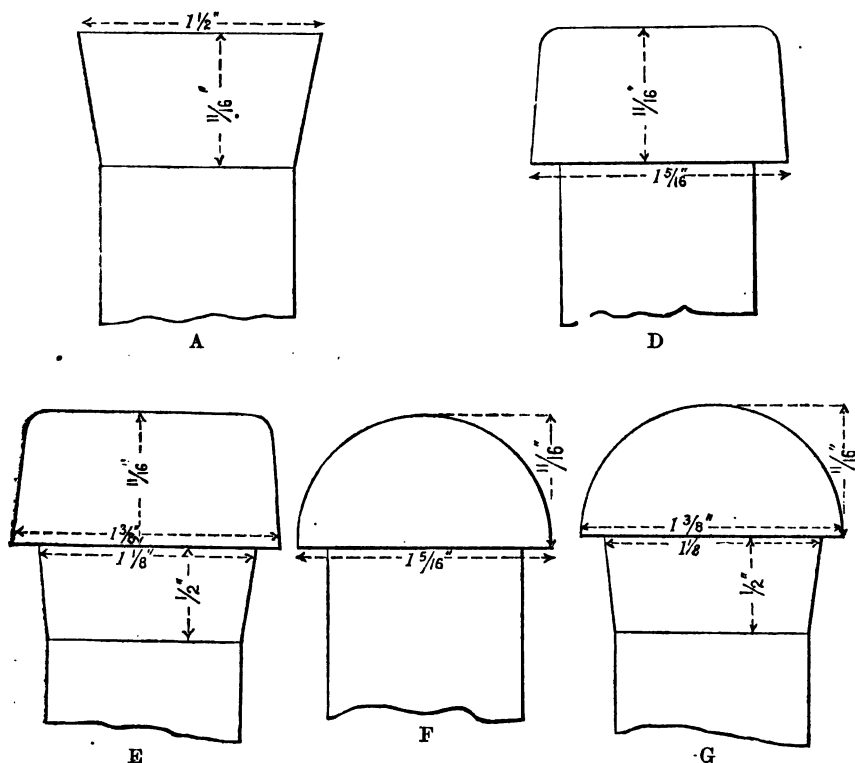
(10) It is important that the whole surface of the bottom plating should be thoroughly cleared of the scale formed in manufacture before any paint or composition is put upon it. Detailed instructions as to the methods of removing the scale are given on NS. 3,590 of January 24, 1881.

ADMIRALTY, September 1, 1881.

BRITISH ADMIRALTY CODE OF TESTS FOR STEEL RIVETS.



(1) The rivets are to be made at the works of a firm approved of by the controller of the navy, and in strict accordance with the dimensions given in the schedule and with the drawings hereunto annexed. Each rivet is to be marked in one place with the broad arrow. They are to be supplied of any length demanded.



Drawings of 1-inch rivets of the several descriptions specified in the schedule herewith.

(2) The rivets are to be made from steel bars having an ultimate tensile strength of not less than 26 and not more than 30 tons per square inch, with a minimum elongation of 20 per cent. in a length of 8 inches. A portion of one bar to be taken for testing from every fifty, or portion of fifty, before making into rivets.

Pieces cut from every bar, heated uniformly to a low cherry-red, and cooled in water of 82° F. must stand bending in a press to a curve of which the inner radius is equal to the radius of the bar tested.

TESTS.

(3) The whole of the said rivets are to be properly heated in making, and care is to be taken that the finished rivets cool gradually. The rivets are to stand the following forge tests:

(a) Bending cold without fracture in the manner shown in Fig. 1 in the annexed diagram, where the line A B equals one diameter of the rivet.

(b) Bending hot without fracture in the manner shown in Fig. 2.

(c) Flattening of the rivet head, while hot, in the manner shown in Fig. 3, without cracking at the edges. The head to be flattened until its diameter is $2\frac{1}{2}$ times the diameter of the shank.

(d) The shank of the rivet to be nicked on one side and bent over to show the quality of the material.

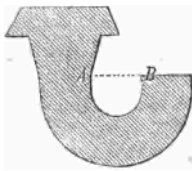


Fig. 1.



Fig. 2.

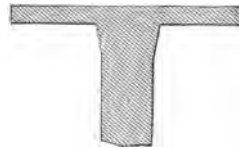


Fig. 3.

One rivet in every hundred to be forge-tested as a sample.

(4) Any such person or persons as their lordships shall from time to time direct or appoint shall be suffered to enter into and inspect the manufactory or works belonging to the maker of the rivets when the said rivets are being manufactured. And such inspector shall be at liberty to test the material to be supplied, in any manner he may see fit, and a proper testing machine shall be kept at the works for this purpose, at the expense of the contractor. Rivets which have passed inspection by the inspector shall be marked by the contractor in any manner the inspector may desire, and when so marked shall not be subject to rejection.

The materials and labor necessary to carry out tests are to be found by the contractor.

Schedule of dimensions.

Diameter of rivet.	With pan or snap heads and straight necks to drawing D or F.		With countersunk heads to drawing A.		With pan or snap heads and conical necks to drawing E or G.			
	Diameter of head.	Depth of head.	Diameter of head.	Depth of head.	Diameter of head.	Depth of head.	Diameter under head.	Depth of cone.
Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
$1\frac{1}{8}$	$1\frac{1}{4}$	1	.....	.....	2	1	$1\frac{1}{2}$	$\frac{1}{2}$
$1\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$
$1\frac{1}{2}$	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{1}{2}$
1	$1\frac{5}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$
$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{7}{8}$
$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{7}{8}$	$\frac{1}{4}$
$\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{8}$	.....	.....	.....	.....	.....	.....
$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{5}{8}$	$\frac{1}{4}$	.....	.....	.....	.....
$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{4}$	.....	.....	.....	.....	.....	.....
$\frac{3}{8}$	$\frac{7}{16}$	$\frac{3}{16}$	.....	.....	.....	.....	.....	.....
$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{8}$	.....	.....	.....	.....	.....	.....

**TESTS FOR PLATE AND OTHER IRON USED IN BUILDING SHIPS FOR
HER MAJESTY'S NAVY.**

ADMIRALTY, July 3, 1890.

PLATE-IRON (FIRST CLASS).

B. B.

Tensile strain per square inch.—Lengthways, 22 tons; crossways, 18 tons.

Forge test (hot).—All plates of the first class, of 1 inch in thickness and under, should be of such ductility as to admit of bending hot to the following angles Lengthways of the grain, 125 degrees; across, 90 degrees.

Forge test (cold).—All plates of the first class should admit of bending cold, without fracture, as follows:

For plate-iron of first class, or B. B., and of middle class.

Thickness of plate.	With the grain.	Across the grain.	Thickness of plate.	With the grain.	Across the grain.
	Through an angle of—	Through an angle of—		Through an angle of—	Through an angle of—
1 inch.....	15	5	$\frac{7}{8}$ inch.....	30	12½
$\frac{7}{8}$ inch.....	15	5	$\frac{1}{2}$ inch.....	35	15
$\frac{3}{4}$ inch.....	20	7½	$\frac{1}{4}$ inch.....	42½	17½
$\frac{1}{2}$ inch.....	20	7½	$\frac{1}{8}$ inch.....	50	20
$\frac{1}{4}$ inch.....	22½	10	$\frac{1}{16}$ inch.....	60	25
$\frac{1}{8}$ inch.....	25	10	$\frac{1}{32}$ inch.....	70	30
$\frac{1}{16}$ inch.....	27½	12½			

PLATE-IRON (MIDDLE AND SECOND CLASS).

B.

Tensile strain per square inch.—Lengthways, 20 tons; crossways, 17 tons.

Forge test (hot).—All plates of the second class, of 1 inch in thickness and under, should be of such ductility as to admit of bending hot, without fracture, to the following angles: Lengthways of the grain, 90 degrees; across grain, 60 degrees.

Forge test (cold).—All plates of the second class should admit of bending cold, without fracture, as follows:

For plate-iron of second class, or B.

Thickness of plate.	Width of grain.	Across the grain.	Thickness of plate.	Width of grain.	Across the grain.
	Through an angle of—	Through an angle of—		Through an angle of—	Through an angle of—
1 inch.....	10	.....	$\frac{7}{8}$ inch.....	25	7½
$\frac{7}{8}$ inch.....	10	.....	$\frac{1}{2}$ inch.....	30	10
$\frac{3}{4}$ inch.....	15	.....	$\frac{1}{4}$ inch.....	37½	12½
$\frac{1}{2}$ inch.....	15	.....	$\frac{1}{8}$ inch.....	45	15
$\frac{1}{4}$ inch.....	17½	5	$\frac{1}{16}$ inch.....	55	17½
$\frac{1}{8}$ inch.....	20	5	$\frac{1}{32}$ inch.....	65	20
$\frac{1}{16}$ inch.....	22½	7½			

Plates, both hot and cold, should be tested on a cast-iron slab, having a fair surface, with an edge at right angles, the corner being rounded off with a radius of half an inch.

The portion of the plate tested, for both hot and cold tests, is to be 4 feet in length, across the grain, and the full width of the plate with the grain.

The plate should be bent at a distance of from 3 to 6 inches from the edge.

It is intended that all the iron shall stand the forge tests herein named, when taken four-feet in lengths, across the grain, and the whole width of the plate along the grain, whenever it may be necessary to try so large a piece, but a smaller sample will generally answer every purpose.

All plates to be free from lamination and injurious surface defects.

One plate to be taken indiscriminately for testing from every thickness of plate sent in per invoice, provided they do not exceed fifty in number, or portion of fifty.

Where plates of several thicknesses are invoiced together, and there are but few plates of any one thickness, a separate test for plates of each thickness need not be made; but no lot of plates of any one thickness must be rejected before one of that lot has been tested.

MOLDED IRON.

Including angle, bulb, tee, angle-bulb, tee-bulb, channel, and other descriptions of molded iron of ordinary form.

Tensile strain per square inch with the grain, for every description, 22 tons.

The ductility and other qualities of the iron should be such as to admit of its being bent hot and cold in the following manner, without fracture:

ANGLE-IRON.

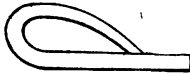
Forge test (hot).—Angle-iron should be tested hot by being bent, thus:



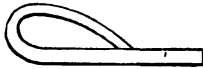
and also by being flattened, thus:



and the end bent over, thus:



Forge test (cold).—Angle-iron should also be notched and broken across cold, to show the quality of the iron, and one flange should be cut off and bent cold, thus:



TEE-IRON.

Forge test (hot).—Tee-iron should be tested hot by being bent, thus:



Forge test (cold).—The cold test for tee-iron should be similar to that for angle-iron.

TEE-BULB IRON.

Forge tests (hot and cold).—Tee-bulb iron should be tested hot by cutting off the bulb and testing the remainder in the same manner as tee-iron, and the bulb should be notched on one side and broken cold to show the quality of the iron.

ANGLE-BULB IRON.

Forge tests (hot and cold).—Angle-bulb iron should be tested in the same manner as angle-iron, after the bulb has been cut off, and the bulb itself should be tested similarly to that of the tee-bulb iron.

BULB IRON.

Forge tests (hot and cold).—Bulb iron should be tested hot by cutting off the bulb and bending with the web across the grain, thus:



and the bulb should be notched on one side and broken cold, to show the quality of the iron.

CHANNEL IRON.

Forge tests (hot and cold).—Channel iron should be tested hot by being bent thus:



and one of the flanges should be cut off and bent cold, as for angle iron. A sample should be notched and broken cold, to show the quality of the iron.

OTHER DESCRIPTIONS OF MOLDED IRON.

Other descriptions of molded iron should be tested in a similar manner to the foregoing, according to the form.

All molded iron to be free from lamination and injurious surface defects.

One sample should be taken indiscriminately for testing from every description of molded iron included in one invoice, provided the number of bars of the same kind so included does not exceed fifty; and if this number is exceeded, one sample is to be taken for every additional fifty or portion of fifty.

BAR AND OTHER IRON.

Including flat or round bar, molding, sash-bar, half-round, and segmental iron, nail-rod iron, hoop-iron, &c.

In this kind of iron that marked "Best Best" should in every case stand a tensile strain, with the grain of 22 tons per square inch, and the whole of the iron should stand such forge tests, both hot and cold, as may be deemed expedient.

The foregoing tests, and such others as may be considered necessary by the controller of the Navy and the overseer, are to be carried out by, and at the expense of, the ship contractors.

TESTS FOR BOILER-PLATE IRON.

Tensile strain per square inch.—Lengthways, 21 tons; Crossways, 18 tons.

Forge test (hot).—All plates of one inch in thickness and under should be of such ductility as to admit of bending hot, without fracture, to the following angles: Length ways of the grain, 125 degrees; across the grain, 100 degrees.

Forge Test (cold).

Thickness of plate.	With the grain.	Across the grain.
	Through an angle of—	Through an angle of—
1 inch	15	5
$\frac{3}{4}$ inch	17.5	6.5
$\frac{2}{3}$ inch	20	7.5
$\frac{1}{2}$ inch	22.5	9
$\frac{3}{8}$ inch	25	10
$\frac{1}{4}$ inch	28	11.5
$\frac{3}{16}$ inch	32.5	12.5
$\frac{1}{8}$ inch	37.5	14
$\frac{1}{16}$ inch	42.5	17.5
$\frac{1}{32}$ inch	48.5	20
$\frac{1}{64}$ inch	55	25
$\frac{1}{128}$ inch	65	30
$\frac{1}{256}$ inch	75	35

REQUIREMENTS FOR STEEL FOR HULLS AND BOILERS OF SHIPS FOR THE FRENCH NAVY.

[No. 52.—The minister of marine and of the colonies to the vice-admirals commanding in chief, maritime prefects, the directors of the establishment d'Indret, and the Forges de la Chaussade. *Second direction*, material; fourth bureau, general supplies; first bureau, naval construction.]

Classification of steel plates and rolled bars—Instructions as to their use and the tests to which they are to be subjected for acceptance.

PARIS, February 9, 1885.

GENTLEMEN: The somewhat extended trial which the navy has made of the circular of May 11, 1876, modified by that of May 7, 1877, permits me to state that the conditions relating to the tensile tests, besides assigning practically too narrow limits to the manufacture, correspond to a quality of steel which was not always sufficiently mild for the purpose intended.

The progress realized for several years in this branch of metallurgy has led me to omit from the new circular the gradations of price assigned to the different classes of steel plates; they were exaggerated, and would occasion, if continued, a sensible loss to the treasury. It is sufficient, in taking account of the difficulties of manufacture, to establish wide divisions, much more simple, for each of which the contractors must fix distinct prices in their tenders.

The new circular contains also certain modifications of less importance, which will be made sufficiently evident by a comparative examination.

Consequently I have decided that the following instructions shall replace those of May 11, 1876, and of May 7, 1877. Its insertion in the official bulletin of the navy will be sufficient notification.

Receive, &c.,

A. PEYRON.

Classification of plates, and of strips and straps, according to their dimensions.

(February 9, 1895.)

Plates are defined by a width greater than 400 millimeters (15½ inches). The denomination of strips and straps [bandes ou couvre-joints] is reserved for those whose width does not exceed 400 millimeters.

SUBDIVISION OF PLATES.

Plates will form four divisions—thin plates, medium plates, thick plates, and extra wide thick plates—as follows:

(1) *Thin* plates, from 1½ millimeters [.059 inch] thick to 4 millimeters [.1575 inch], exclusive, of 1.60 meters [63 inches] maximum width and 7 meters [22 feet 11.6 inches] maximum length.

(2) *Medium* plates, from 4 millimeters [.1575 inch] to 8 millimeters [.315 inch] thick, exclusive of 1.80 meters, [70½ inches] maximum width, and 8 meters [26 feet 3 inches] maximum length.

(3) *Thick* plates, from 8 millimeters [.315 inch] thick and above, of 1.80 meters [70½ inches] maximum width, and 10 meters [32 feet 9½ inches] maximum length.

(4) *Extra wide thick* plates of 8 millimeters [.315 inch] and over in thickness, between 1.80 meters [70½ inches] and 2.10 meters [82¼ inches] wide, and a maximum length of 10 meters [32 feet 9½ inches].

Plates not rectangular, but with straight sides, may be demanded, and will be paid for at the rate of 3 francs per 100 kilograms [about ½ cent per pound] more than the rectangular plates from which they were cut.

SUBDIVISION OF STRIPS AND STRAPS.

(1) *Thin* strips, from 1½ millimeters [.059 inch] to 4 millimeters [.1575 inch], exclusive, and of 7 meters [22 feet 11½ inches] maximum length.

(2) *Medium* strips, 4 millimeters [.1575 inch] to 8 millimeters [.315 inch] thick, exclusive, and of 8 meters [26 feet 3 inches] maximum length.

(3) *Thick* strips, 8 millimeters [.315 inch] and over thick, and of 10 meters [32 feet 9½ inches] maximum length.

Forms of tenders, inserted after the conditions of contract, will be made so that bidders may affix a price for each of these subdivisions.

Extra thin plates and strips below 1½ millimeters [.059 inch] thick, and thin, medium, and thick plates and strips, which, by their width and length, may not be comprised in the above classification, will be the subject of special contracts.

TESTS OF ACCEPTANCE.

To insure the quality of steel plates and strips, three kinds of tests will be made: (1) cold tests; (2) hot tests; (3) temper tests.

(1) *Cold tests*.—The object of these tests will be to determine the resistance of the metal to rupture and its capacity for elongation both with and across the grain (always provided the width is sufficient).

The mean results of resistance and elongation in these two directions will be separately obtained, by at least five tests for each.

For these tests, pieces will be cut from a certain number of sheets or strips taken at random from each delivery. These pieces will be fashioned so as to have a rectangular section of which the smaller side is the thickness of the piece, and the longer side will be 30 millimeters [1.181 inch] for plates of 4 millimeters [.1575 inch] and over, and 20 millimeters [.7874 inch] for plates of less than 4 millimeters [.1575 inch], i. e., for plates called *thin*. However, for plates of 20 millimeters [.7874 inch] and over, the width should be equal to the thickness, so that the section of the piece will be a square of side equal to the thickness.

The length of the prismatic portion taken for tension will be always exactly 20 centimeters (7.874 inches) laid off by two punch marks, and terminating in fillets, so that rupture may always take place between the punch marks.

On no account may the pieces be reheated after being removed from the sheets.

Each piece shall be subjected to an initial load determined so as to produce a stress equal to eight-tenths of the breaking stress calculated according to the accompanying tables. This first load will be maintained in action for one minute, unless the piece continues to stretch after this lapse of time, when no further load will be added until the elongation ceases.

At intervals of a quarter of a minute successive loads will be added of one-half kilo-

gram per square millimeter (711 pounds per square inch); these intervals may always be prolonged when necessary, *i. e.*, so that no additional load may be added while the piece continues to stretch under the preceding load. The elongation corresponding to each load will be noted as measured on the length of 20 centimeters between punch marks.

No test piece considered satisfactory is to break under the initial load, whatever the corresponding elongation; nor give a final elongation less than eight-tenths of the final elongation demanded, whatever may be the corresponding breaking load.

The least mean breaking loads per square millimeter of original section, and the least elongations per cent. demanded of pieces subjected to test, are given in the annexed Table I. for plates, and in Table II. for strips and straps.

It will be observed that for plates no distinction is made between the results demanded with and across the grain. The figures of Table I. are to be obtained for both directions.

Not so for strips. Here, indeed, from the method of rolling, the strength and elongation with the grain should be greater than across it; besides, for narrow strips, in most cases test pieces cannot be taken across the grain. Accordingly Table II. has different figures for the two cases.

TABLE I.—*Plates.*

Thickness.		Ship plates.			Boiler plates.		
		Least mean stress.		Least mean final elongation.	Least mean stress.		Least mean final elongation.
Millimeters.	Inches.	Kilos. per sq. mm.	Lbs. per sq. inch.	Per cent.	Kilos. per sq. mm.	Lbs. per sq. inch.	Per cent.
1½ to 2 ...	.059 to .079, exclusive ...	47	66,830	10	.....	.....	.....
2 to 3 ...	.079 to .118, exclusive ...	46	65,420	13	.....	.....	.....
3 to 4 ...	.118 to .1575, exclusive ...	45	63,990	16	.....	.....	.....
4 to 6 ...	.1575 to .236, exclusive ...	45	63,990	18	45	63,985	22
6 to 8 ...	.236 to .315, exclusive ...	43	61,150	21	42	59,720	25
8 to 20 ...	.315 to .787, exclusive ...	42	59,730	22	42	59,720	26
20 to 30 ...	.787 to 1.181, inclusive ...	42	59,730	24	40	56,880	26

A reduction will be allowed in the least mean resistance up to 2 kilograms (2,844 pounds) provided this deficiency is compensated for by such an increase of elongation that the sum of the resistances and elongations is not less than as given in the table.

Not the least reduction of elongation will be allowed.

TABLE II.—*Strips or straps.*

Thickness.		Lengthways.			Crossways.		
		Least mean stress.		Least mean final elongation.	Least mean stress.		Least mean final elongation.
Millimeters.	Inches.	Kilos. per sq. mm.	Lbs. per sq. inch.	Per cent.	Kilos. per sq. mm.	Lbs. per sq. inch.	Per cent.
1½ to 4 ...	.059 to .1575, exclusive ...	47	66,830	13	45	63,990	12
4 to 6 ...	.1575 to .236, exclusive ...	46	65,410	19	44	62,570	17
6 to 8 ...	.236 to .315, exclusive ...	44	62,570	22	42	59,720	20
8 to 20 ...	.315 to .787, exclusive ...	43	61,140	23	41	58,300	21
20 to 30 ...	.787 to 1.181, inclusive ...	43	61,140	25	41	58,300	23

A reduction will be allowed in the least mean resistances to the same extent and with the same compensation of elongation as for plates.

(2) *Hot tests.*—The test will consist in forming from a piece of plate of suitable dimensions a hemispherical cup, with a flat rim retained in the original plane of the plate.

The diameter of the hemisphere, measured on the inside, is to be equal to forty times the thickness of the plate, and the width of the flat circular rim is to be ten times this thickness. This flat rim is to join on to the spherical part by a bend, of which the radius, measured on the inside of the angle, shall be, at most, equal to the thickness of the plate.

Besides this, for plates of more than 5 millimeters thickness there shall be fashioned a box with a square base, with the sides at right angles with the plane of the plate; the base of this box shall have for its side thirty times the thickness of the plate, and the raised rims, measured on the inside, shall have for their height ten times this thickness. The bottom of this box shall be pierced in the middle with a circular hole, with edges raised at right angles to the plane of the bottom, and on the opposite side to that of the rim of the box. The diameter of this hole, measured on the inside after the work is done, is to be twenty times the thickness of the plate, and the height of the raised edge is to be five times this thickness. All angles are to be rounded, their internal bend having for radius the thickness of the plate.

The pieces so fashioned, with all the precautions required in working steel, must present neither flaws nor cracks even after cooling in a strong current of air.

The box test is not obligatory, but is left to the discretion of the engineer in charge.

(3) *Temper test.*—For these trials, pieces will be cut from the sheets presented for acceptance 26 centimeters (10½ inches) long by 4 centimeters (1.575 inches) wide, both with and across the direction of rolling; for strips and straps they will be taken only lengthways. The pieces prepared for these tests are not to have their long edges rounded off, the only treatment permitted being to remove the sharpness of the edges with a fine file. They will be uniformly heated so as to be brought to a low cherry red, and then plunged in water at 28° centigrade. Thus prepared they are to take under a press, without sign of rupture, a permanent bend of least internal radius not exceeding the thickness of the piece tested.

Similar pieces when taken from boiler plates must stand, under a press, without sign of rupture, being folded over flat, so that the two halves shall be in perfect contact with one another.

Plates which will not satisfy the conditions detailed above will be rejected.

ROLLED BARS.

To insure the quality of the different kinds of rolled bars of steel, three kinds of tests will be made as for plates: cold tests, temper tests, and hot tests.

(1) *Cold tests.*—The object of these tests will be to determine the resistance of the metal to rupture and its capacity for elongation. For this purpose, pieces will be cut from the webs under the same conditions as for steel plates. The thickness shall be that of the webs, the width the same as for steel plates of the same thickness, i. e., 30 millimeters for webs of 4 millimeters in thickness and over, and 20 millimeters for webs less than 4 millimeters thick.

The initial load will be determined so as to produce a tensile stress equal to eight-tenths of the breaking stress calculated from the following table.

The tests will be then conducted as prescribed for plates.

No piece considered satisfactory is to break under the initial load nor give a final elongation less than eight-tenths of the mean final elongation required.

The least mean stresses per square millimeter of original section, under which the pieces may break and the corresponding least elongation are given in the following table:

Thickness of webs.			Angles, bulb-bars, and plain T-bars.			Bulb-beams H; U, and Z-bars.			Angles for boilers.		
			Least mean stress.	Least mean final elongation.		Least mean stress.	Least mean final elongation.		Least mean stress.	Least mean final elongation.	
M. m.	Inches.		Kilos per sq. m. m.	Lbs. per sq. in.	Per ct.	Kilos per sq. m. m.	Lbs. per sq. in.	Per ct.	Kilos per m. m.	Lbs. per sq. in.	Per ct.
2 to 4.	.079 to .1575, exclusive	...	46	65, 410	18	46	65, 410	18	46	65, 410	22
4 to 6.	.1575 to .236, exclusive	...	44	62, 570	22	44	62, 570	20	46	65, 410	22
6 to 8.	.236 to .315, exclusive	...	44	62, 570	22	44	62, 570	20	44	62, 570	26
8.....	.315 and over	...	42	59, 720	24	44	62, 570	22	42	59, 720	26

The same reduction of 2 kilograms in the minimum breaking stresses is allowed as for plates, under the same conditions of increase of the corresponding final elongation. No reduction whatever is allowed in the elongations.

(2) *Temper tests.*—For these tests there shall be cut from the webs of bars presented for acceptance strips 26 centimeters ($10\frac{1}{2}$ inches) long and 40 millimeters (1.575 inches) wide, with the same precautions as for plates. As for the latter, they will be heated to a low cherry red and plunged into water at 28° centigrade. They must be able to take under a press a permanent set of internal radius not greater than $1\frac{1}{2}$ times the thickness of the bar tested, except for angles for boilers. These must stand being bent to an inner radius at least equal to their thickness.

(3) *Hot tests.*—Angles will be subjected to the following tests:

A piece cut from the end of a bar taken at random from each delivery shall be formed into a ring such that one flange remaining in its own plane, the other flange forms a cylinder of internal diameter equal to three and a half times the width of the flange remaining flat. A piece cut from the end of another bar shall be opened out until the two faces are practically in the same plane. A piece from the end of a third bar shall be closed until the two flanges are in contact. The angles subjected to these tests must show neither cracks, cliffs, nor flaws.

Channel (**L**) and **Z** bars will be subjected to the same tests, the middle web being split for a suitable distance so as to get an angle with equal flanges.

Single **T** bars will be subjected to the following tests:

A piece cut from the end of a bar taken at random from each delivery shall be formed into a half ring such that the central flange remaining in its own plane the other may form a half cylinder of internal diameter equal to 4 times the depth of the **T**.

At the end of another bar taken by chance from the same delivery the central flange will be split up the middle for a length equal to 3 times the total depth of the bar and a hole drilled at the end of the slit to prevent its spreading; the piece so separated shall be opened out in its own plane to an angle of 45° with the other flange. Care must be taken to keep the flange opened out reasonably straight, it being joined on to the rest of the bar with a curve of small radius.

The bars subjected to these tests must show neither cracks, cliffs, nor flaws.

Bulb **T** and **I** beams will be subjected to the following tests: At the end of a bar selected at random from each delivery, the central web will be split up the middle for a length equal to three times the total depth of the bar, and a hole drilled at the end of the slit to prevent its spreading; then one of the two parts shall be opened out at one or more heats, the central flange remaining in its own plane, so that the two pieces make an angle of approximately 45° with each other. For bulb bars the part bent out shall be that which carries the bulb. Care must be taken to keep the part worked sensibly straight, and to join it on to the rest of the bar with a curve of small radius.

Angles and molded bars which will not satisfy these conditions will be rejected.

A. PEYRON.

Minister of Marine and of the Colonies,

PARIS, *February 9, 1885.*

TESTS OF STEEL REQUIRED BY LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING.

The steel to be used in ships building for classification in the register book will be required to withstand the whole of the following tests, to be applied at the steel works under the personal inspection of the society's surveyors, to samples selected by them from every charge or cast employed in the manufacture of the material, and these samples, when marked by them for testing, should be followed by the surveyors through the different stages of preparation until the tests are completed.

The committee will require that every plate, beam, and angle supplied for these ships shall be clearly and distinctly stamped by the manufacturer in two places, where the brand cannot be conveniently sheared off, after they have been tested, the brand to be similar to the following, thus: Denoting that a shearing from the plate or an-

R

gle so marked has successfully been bent cold after being tempered as described in the temper test which follows, and that the plate or angle in question is capable of withstanding the whole of the tests hereafter described; and the committee will require the surveyors when in constant attendance at the steel works to satisfy themselves, so far as may be practicable, that these conditions are being complied with in a *bona fide* manner.

Should the samples selected by the surveyor not fulfill the test requirements, the plates or angles from which they were cut are to be rejected, and further tests are to be made before any material from the same charge can be accepted.

When one of the society's surveyors is not in constant attendance at the steel works for the purpose of seeing the material tested, the committee will require that tensile and temper tests shall be applied either at the steel works or at the ship-yard to not less than one plate, angle bar, or bulb plate, in every batch of 50, or a batch of less number; but the surveyor is not to select samples for testing until the material has been tested, stamped, and appropriated by the manufacturer. The samples when marked by the surveyor for testing are to be followed by him when practicable through the different stages of preparation until the tests are completed. Should the samples tested not fulfill the test requirements, the whole of the material from the charge which produced the samples which failed to withstand the tests prescribed is to be rejected or retested, and further tests are to be applied to a sample from each of the other charges of which the batch is composed. In the event of any of these samples also failing, the whole of the material from the same charge or charges is to be rejected as in the first instance.

Before these sample tests have been applied to a batch of steel submitted for check testing, the surveyor is to be furnished with a certificate by the manufacturer to the effect that the society's requirements as to the testing of steel have been complied with in the case of the batch in question.

In the event of material failing, in any case, to withstand the prescribed tests, the brands approved by the committee and stamped on the plates, beams, and angles by the manufacturer are to be defaced by punch marks extending beyond the brand in the form of a cross, thus: denoting that the material is rejected.



The society's surveyor will require to have every facility placed in his way for tracing all plates, beams, and angles to their respective charges, and to be furnished with two copies of the advice notes of the material, one of which, when he shall have been satisfied with the results of the tests applied to the material, he is to sign, to be forwarded by the manufacturers to the ship-builders, and the other of which is to be retained by himself.

TESTS.

Strips cut lengthwise or crosswise of the plate, and also angle and bulb steel, to have an ultimate tensile strength of not less than 27, and not exceeding 31 tons per square inch of section,* with an elongation equal to at least 16 per cent. on a length of 8 inches before fracture.

Strips cut from the plate, angle or bulb steel, to be heated to a low cherry-red, and cooled in water of 82° Fahrenheit, must stand bending double round a curve of which the diameter is not more than three times the thickness of the plates tested.

In addition to this, occasional angle bars should be subjected to a cold test by having pieces cut off and bent flat and then doubled backwards.

RIVETS.

The steel used for rivets to be of special quality, soft and ductile, and samples of the rivets should be tested by being bent both hot and cold, by flattening down the

* Steel angles intended for the framing of vessels, and bulb steel for beams, may have a maximum tensile strength of 33 tons per square inch of section, provided they be capable of withstanding the bending tests, and of being efficiently welded.

MEM.—No reduction will be allowed in the sizes of rivets from those which would be required by the rules for the vessels if built of iron.

heads, and by occasional forge tests, in order to satisfy the surveyors of their thorough efficiency.

BOILERS MADE OF STEEL.

The use of steel will be sanctioned in the construction of boilers intended for vessels classed or proposed for classification in the Society's Register Book, provided the boilers be constructed in accordance with the requirements of the rules, and the following conditions be fulfilled.

The material is to have an ultimate tensile strength of not less than 26 and not more than 30 tons per square inch of section, with an ultimate elongation of not less than 20 per cent. in a length of 8 inches. It is to be capable of being bent to a curve, of which the inner radius is not greater than one and a half times the thickness of the plates or bars, after having been heated uniformly to a low cherry-red and quenched in water of 82° F.

Steel rivets are to be considered as part of the material, and in addition to being subjected to a shearing test, they must be capable of withstanding the same tests as the plates are required to undergo.

Samples for testing are to be selected from each batch of plates submitted for approval, care being taken in the selection that, as far as possible, each cast or furnace charge, from which the material has been produced is represented. In addition to these tests, the temper test is to be applied to samples taken from *every* plate intended to be used in the furnaces and combustion chambers of the boilers.

The society's surveyor will attend at the steel works when necessary, and select the samples for testing before the plates are sheared to size, and these samples when marked by him for testing should, as far as practicable, be followed by the surveyor through the different stages of preparation until the tests are completed.

The society's surveyor will require to have every facility placed in his way for tracing all plates to their respective charges, and to be furnished with two copies of the advice notes of the material, one of which, when he shall have been satisfied with the results of the tests applied to the material, is to be signed and forwarded to the boiler manufacturer, and the other is to be retained by himself.

The samples are taken for testing in order that the general quality of the material may be ascertained, and if any sample should fail to fulfill the conditions laid down, the plate from which the sample is taken must be rejected; and further tests should be made before any material made from the same cast or charge as the failing sample can be approved.

All the holes in steel boilers should be drilled, but if they be punched the plates are to be afterwards annealed.

All plates that are dished or flanged, or in any way heated in the fire for working, except those that are subjected to a compressive stress only, are to be annealed after the operations are completed.

No steel stays are to be welded.

Unless otherwise specified, the rules for the construction of iron boilers will apply equally to boilers made of steel.

"LIVERPOOL UNDERWRITERS' REGISTRY." (RULES FROM SEPTEMBER 1, 1882, to AUGUST 31, 1883.)

VESSELS BUILT OF STEEL.

SECTION 24. The whole of the material used in construction of the hulls of such vessels, except where otherwise specified, or by special sanction of the committee, must be of steel of "mild" quality, and capable of withstanding the following tests:

Samples are to be selected by the surveyor, in such numbers as he may deem necessary, but samples must be taken at least from every cast, and from every fifty plates or bars, and tested as follows:

Strips cut lengthways and crossways of plates, and lengthways of bulbs, bars, and angles, are to have an ultimate tensional resistance of not less than 30 tons per square inch. The prepared parallel part of the tension sample must not be less than eight inches long. Strips cut lengthways and crossways of plates, and lengthways of bulbs, bars, and angles, are to be heated to a full red and quenched in water, and then bent cold double without fracture, with a curvature of which the inner radius does not exceed one and a half times the thickness of the sample.

Strips with sheared edges undressed, heated and quenched as above described, and similar strips without any tempering, are, at the discretion of the surveyor, to be

tested by being bent cold without fracture through an angle of not less than 120° , with a curvature at the angle of which the inner radius does not exceed one and a half times the thickness of the sample.

Occasional samples of plates, bulbs, bars, and angles are to be punched and sheared, in accordance with ordinary ship-building practice, and are then to be treated in ordinary ship-yard fashion, under the direction of the surveyor, without failure in any respect.

Angle and tee bars are to be submitted to opening and closing and ram's horn tests, as the surveyor may direct.

Rivet-steel may be of about 28 tons per square inch tensional resistance, and both the material and the manufactured rivets must be subjected to such hot and cold bending and other tests as the surveyor may direct.

In the event of any samples failing in any of the foregoing tests, the plates, bulbs, bars, and angles from which they are taken shall be rejected, and such further tests made as the district chief surveyor may direct, under the circumstances, before any material from the same cast may be accepted.

If desired, the steel may be tested in the presence of the surveyor at the steel-maker's works, in which case invoices in duplicate are to be furnished for certification by the testing surveyor, and every facility is to be afforded him for identification of the plates and bars with the representative test samples and the respective casts from which they have been made. The steel is not to be used at the ship-yard until it has been satisfactorily tested and the invoice, certified by the surveyor, has been produced.

Should any of the material fail in any way in course of being worked into the ship, the surveyor is to be at liberty to submit it to such further tests as the circumstances may dictate, reporting the results to the district chief surveyor, who may reject any defective material, notwithstanding any previous certificate of satisfactory testing.

"BUREAU VERITAS" RULES FOR 1882.

STEEL VESSELS.

ARTICLE 33, SECTION 1. The scantlings of steel vessels will generally be regulated by the rules for the construction of iron vessels.

SEC. 2. The steel used in the construction of the vessels must comply with the following requirements:

(1) All steel plates, angles, and bulbs to be legibly stamped with a special mark, which shall indicate the guarantee of the manufacturer that the material is of the quality required by the rules. This mark to be so placed that it will be visible on the plate or bar, when riveted up in the ship.

(2) The steel to have an ultimate tensile strength of from 27 to 32 tons per square inch, and an elongation at rupture of at least 20 per cent. on a length of 200 millimeters ($7\frac{7}{8}$ inches).

(3) Strips about 2 inches wide, cut from the plates, bulbs, and angle bars, after being heated to a dull red and cooled in water at 28° C. (82° F.), shall withstand, without fracture, being doubled over and closed until the width of the opening near the bend is equal to three times the thickness of the sample tested.

SEC. 3. The following reductions may be allowed:

(1) 18 to 25 per cent. on the outside plating, sheer strakes, garboards, water-tight bulkheads, stringers, ties, and keelsons.

(2) 10 to 15 per cent. on the thickness of the floors, bulbs, and angles. These reductions may be greater should the system of construction followed provide a moment equivalent to that exacted in iron vessels.

SEC. 4. The diameter of the rivets, their spacing, and the system of riveting, also the width of laps and butt-straps, should be determined according to the rivets for iron vessels, from the tabular scantlings, and irrespective of the scantlings allowed. The butts of the outside plating to be treble riveted for half the vessel's length amidships, when the number is 200,000 or above, and for two-thirds the length when the number is 300,000 or above.

SEC. 5. Forged iron will be accepted for keel bars, stem, and stern post, for the rudder-head and frame and for pillars.

SEC. 6. A midship section and a longitudinal section, of vessels to be built of steel, shall accompany the request for classification, in order to be submitted for the approval of the Direction.

EXTRACTS FROM SPECIFICATIONS OF RAILROAD BRIDGE OVER THE OHIO RIVER AT HENDERSON, KY.

WROUGHT IRON.

Elastic limit to be not less than 26,000 pounds per square inch.

Iron for tension members, best double-rolled, refined iron, to stand the following tests:

Full-size pieces of flat, round, or square iron, not over $4\frac{1}{2}$ square inches sectional area, shall have an ultimate tensile strength of not less than 50,000 pounds, and shall stretch not less than $12\frac{1}{4}$ per cent. in the whole length.

Bars of more than $4\frac{1}{2}$ square inches sectional area will be allowed a reduction of 1,000 pounds per square inch, for each additional square inch, down to a minimum of 46,000 pounds.

When tested in specimens taken from the above, the ultimate tensile strength shall not be less than 52,000 pounds, with 18 per cent. stretch for bars whose original area was $4\frac{1}{2}$ square inches or less, and for bars whose original area was greater than $4\frac{1}{2}$ square inches, a reduction of 500 pounds for each additional square inch of section will be allowed down to a minimum of 50,000 pounds.

From angle or shape iron, not less than 50,000 pounds, with 15 per cent. stretch in 8 inches.

From plate, not less than 48,000 pounds, with 15 per cent. of stretch.

Iron for tension members must bend cold to 180° to a curve whose inner diameter is 2 thicknesses. Cooled off with ice to 30° F., nicked on both sides, and bent under a sledge, it shall bend and break gradually with uniform fibrous fracture. Specimens from angles, plates, and shape iron shall bend cold to 90° to inner diameter of not more than 3 thicknesses.

STEEL.

To be manufactured by the open-hearth process. Bessemer steel will not be accepted.

A small ingot shall be cast from every charge, and a sample bar, $\frac{1}{2}$ -inch, rolled from it. If this bar fails to meet requirements of laboratory tests the whole charge shall be rejected.

Ingot of each cast, and blooms and finished pieces, shall be marked with the number of the cast.

Steel used in compression members, bearing plates, pins, and rollers shall contain not less than .34 per cent. nor greater than .42 per cent. carbon, and not more than .10 per cent. of phosphorus.

A sample bar, $\frac{1}{2}$ -inch in diameter, shall bend to 180° around its own diameter.

The same bar in a lever machine shall show an elastic limit of not less than 50,000 pounds, and an ultimate tensile strength of not less than 80,000 pounds, with an elongation of 15 per cent. in 8 inches, and a reduction of area of at least 30 per cent. at fracture. Shall be incapable of tempering.

Steel for rivets and eye-bars shall contain not more than .26 per cent. carbon and less than .10 per cent. phosphorus. A $\frac{1}{2}$ -inch round bar shall close to 180° , and in a lever machine shall have an elastic limit of not less than 40,000 pounds, and an ultimate tensile strength of not less than 70,000 pounds, with an elongation of not less than 20 per cent. in 8 inches, and a reduction of area of not less than 40 per cent. at fracture. In full-size bars, this steel shall show an elastic limit of not less than 36,500 pounds, and an ultimate tensile strength of not less than 66,000 pounds, with an elongation of not less than 10 per cent., and for strains greater than 30,000 pounds shall have modulus of elasticity of from 28,000,000 to 30,000,000.

All plates to be rolled in a universal mill.

Steel for pins shall not be hammered, but rolled in Gothic rolls.

Riveted steel work.—The holes shall be punched enough smaller than the diameter required for the rivet to admit of $\frac{1}{16}$ -inch riming all around after assembling. Sharp edges of round hole to be trimmed to a slight fillet under rivet heads, and the piece riveted together without being taken apart. All rivets in steel members will be of steel.

Annealing.—After working, eye-bars shall be annealed by heating them to a uniform dull red heat and allowing to cool slowly.

Friction rollers.—Wrought iron—pressure in pounds per linear inch of rollers shall not exceed $\sqrt{540000 \times d}$, where d = diameter of roller in inches. For steel rollers an addition of 25 per cent. may be made to the above pressures.

Pitch of rivets.—In compression members, from center to center not more than 6 inches, or 16 times the thickness of any of the joined plates, and for a distance of two

diameters from the ends to be 4 diameters of rivet; in no case shall the pitch be less than 4 diameters of rivet.

Distance between edge of any piece and center of rivet hole must not be less than $1\frac{1}{4}$ inches except in bars less than $2\frac{1}{4}$ inches wide; where practicable it shall be at least 2 diameters of rivet.

Pin strains.—For shearing not greater than 7,000 pounds for wrought iron, or 10,000 pounds for steel. Maximum fiber strain from bending shall not be greater than 15,000 pounds for wrought iron, or 20,000 for steel.

Bearing strain on area = diameter by thickness of head, shall be not greater than 12,000 pounds for wrought iron or 18,000 for steel.

Rivets.—Shearing stress not greater than 7,000 pounds for wrought iron or 10,000 pounds for steel; bearing strain 10,000 pounds for wrought iron and 15,000 pounds for steel, for all rivets in bearing and splice plates; elsewhere 12,000 pounds for iron and 18,000 for steel.

Combined strains.—In members subjected to combined compression and tensile strains, the maximum compressive stress shall be not greater than 7,000 pounds per square inch.

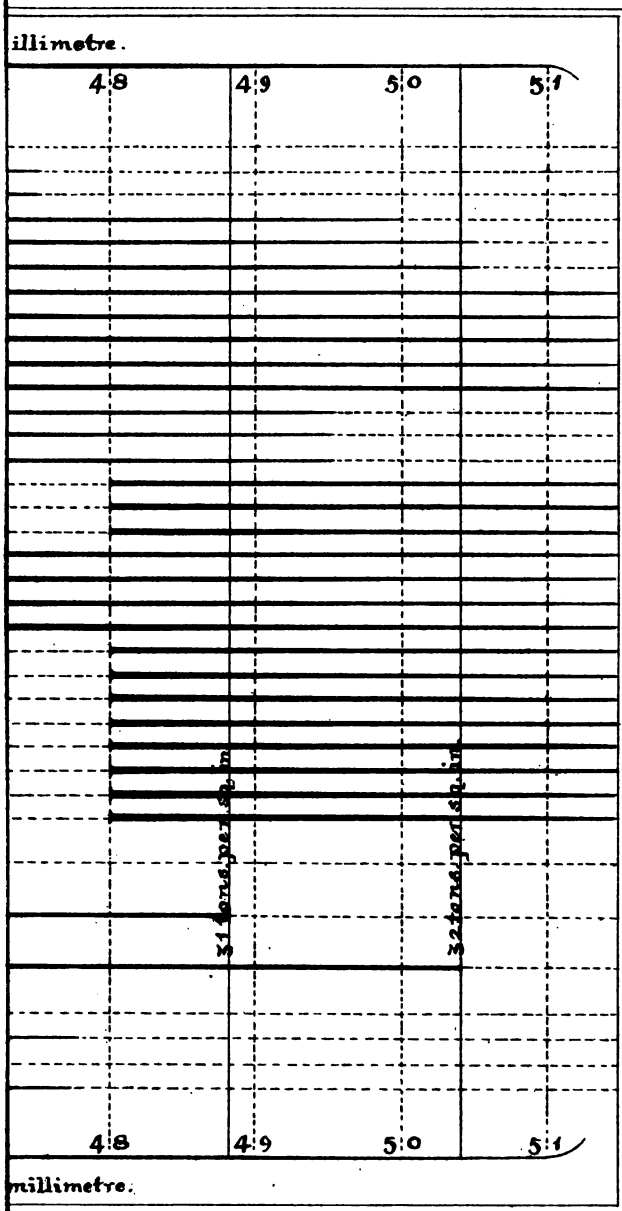
Tensile strains.—For wrought iron tension members and rolled beams 10,000 pounds. Bottom flanges of riveted girders 8,000 pounds net section.

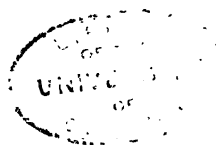
Steel tension members 14,000 pounds.

Compressive strains.—In steel compression members up to 16 diameters in length, 14,000 pounds. For a greater ratio, $\frac{1}{4}$ ths of the results for wrought iron as given in a table accompanying.

Factor of safety, 5.

TS for STEEL.





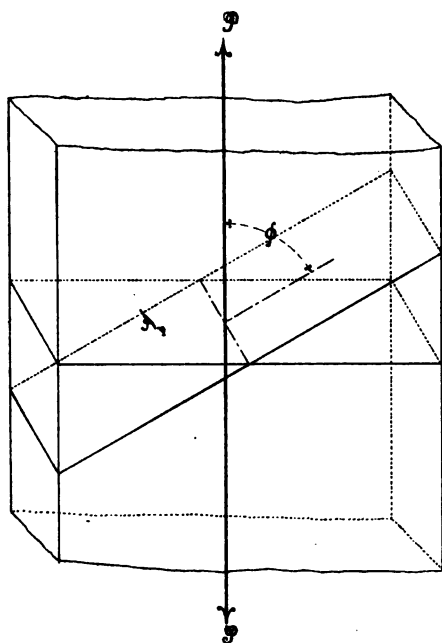


Fig. 18

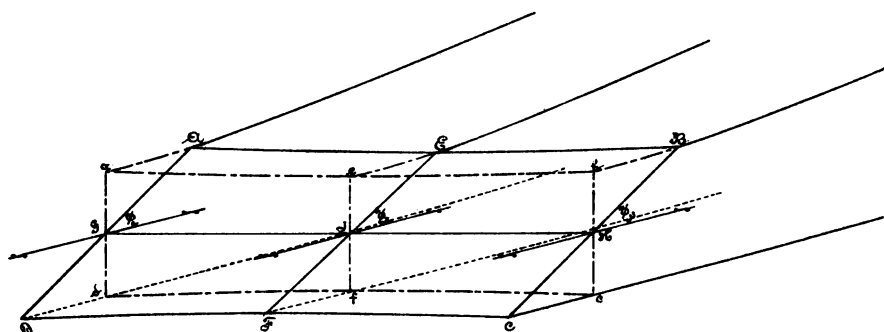


Fig. 19

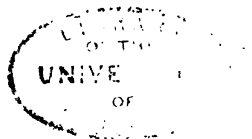


INDEX.

	Page
Admiralty instructions for treatment of mild steel.....	197
requirements for steel for hulls and boilers.....	196
tests for iron for boilers and hulls.....	200
tests for steel rivets	198
Annealing	160
method in use at Norway Iron Works.....	165
precautions to be observed in	166
effects of, Table XXXIV.....	161
of boiler plates at steel works, proposed restrictions on	100
Annealed material, test pieces of	35
Angle bulb, proposed	176
Area, final, measurement of	139
Beam sections, properties of certain, Table XL	176
Black Diamond steel, process of manufacture, chemical tests, &c.....	53
Blooms, sizes of, for shapes.....	58
Boilers, admiralty requirements in steel for.....	196
locomotive, on Pennsylvania Railroad, steel for	5
naval, mild steel for	7
Boiler plates, tests for, prescribed by Advisory Board	20
annealing of, at steel works restricted	100
Boiler-shop and ship-yard, steel in the.....	77
Bridges, railroad, specification of steel for	212
mild steel for, in the United States.....	9
"Bureau Veritas," rules of, for steel ships	211
Cambria steel, process of manufacture, chemical tests, &c.	57-75
Carbon, combined, color tests for	179
Carbon properties, curves of	185-191
of Chester steel, Table XLI.....	188
Norway steel, Table XLII.....	189
Cambria steel, Table XLIII.....	190
Castings, steel, admiralty tests for	197
Chester steel, process of manufacture, chemical tests, &c	35-44
Chemical analysis, methods in American steel works	179
requirements	177
tests at Chester Mills	38
Norway Mills.....	47
Cambria Iron Works	68
Color tests for combined carbon	179
Cooling, strains due to.....	127
Copper in steel, determination of amount of.....	185
Deck-beams and T's, new sections of, and considerations of their properties.....	173
Determination of amount of copper.....	185
manganese	183
phosphorus.....	181

	Page.
Modulus of elasticity	134
Natural gas, use of, at Black Diamond Steel Works.....	53
Navy, French, requirements for material in	26
tests of steel for hulls and boilers in	204
United States, considerations leading to use of steel in	13
mild steel in use in boilers of, to January 1, 1884.....	8
Norway Iron Works, method of annealing at	165
tensile tests of steel from.....	47
process of manufacture, chemical tests, &c	44
Oxide of iron in steel	185
Phœnixville, method of testing at	62
Riehle testing machine at.....	60
Phœphorus, effect of, on elastic limit	133
effect on general qualities of steel	192
methods of determination of	181
Physical tests of steel forgings.....	86
Proportion, law of, in test pieces of various forms and sizes.....	116
Punching, effects of	169
Quenching tests.....	166
difficulties with, at Black Diamond Works	55
apparatus for, at Chester	36
Ratio, elastic, of various steels.....	133, 149
as a measure of physical condition	127, 192
Record of tests, proposed form for	105, 107
Reduction of width and of thickness in section of test piece.....	141
Requirements for steel for use in Great Britain.....	25
French navy.....	26
Rivets, admiralty tests for steel.....	198
dimensions of steel.....	199
specimens of test pieces of.....	80
strength of, in single and double shear.....	80
shearing strength of.....	146
steel for and inspection of	79
and rivet bars, tests of	81, 85
Rules of Bureau Veritas for use of steel in hulls	211
Sections, new, of deck beams and T's.....	173
proposed Z and angle bulb	176
Shear, fracture by.....	141
Shearing force, to calculate from tensile tests.....	142
Shearing strength of rivets.....	146
Shipbuilding, admiralty requirements in steel for	196
mild steel for, in United States	9
Ship plates, tests prescribed by Advisory Board	19
Ship-yard and boiler-shop, steel in the.....	77
Silicon, determination of amount of.....	184
Sulphur, determination of amount of	185
Strains due to cooling.....	127
Strain diagrams	147
Cambria ship steel.....	151
Chester ship steel.....	153
Black Diamond ship steel.....	154
Norway ship steel.....	155
T's and deck beams, new sections of.....	173
Tensile limit, elongation at.....	138
definition of.....	129

	Page.
Tests, admiralty, of steel for hulls and boilers	196
for steel rivets	198
of iron for hulls and boilers	200
comparative, by cold bending and quenching	168
comparison of machines	156
commercial, object of	108
of material, details of method of, at Johnstown	60
Phoenixville	62
first code prescribed by Advisory Board	20
modification of first code	27
in French navy	26
proposed new code of	97
forms for record of	105
recommendations of inspectors regarding changes in re- quirements	89
suggestions of manufacturers regarding	22
summary of	75
Testing machines	36, 45, 59, 60
Test piece, physical and chemical condition of	126
straining the	128
extension of the	136
fracture of	138
of annealed material	35
length of, influence of	121
proportions of round and flat	113, 115
physical, for steel forgings	86
Tests, quenching	166
apparatus for, at Chester	36
difficulties with, at Black Diamond Works	55
rules of, for French navy, hulls and boilers	204
Lloyd's Register, hulls and boilers	208
Liverpool's Underwriters' Registry, hulls and boilers	210
shearing of rivets	81-85
special, open and closed, for beams and T's	176
tensile, Tables IV to IX	40, 47, 55, 64, 68, 71
fast and slow, on same material	124
forms and dimensions of pieces for	110
by increments and by continuous loads	121
Treatment of mild steel, admiralty instructions for	197
Weights, limits of, in rolling	32
modifications of	34
Work of reduction, effect of, on elastic limit	133
on tensile strength and ductility	127
Working, failures in, at yards	77
Z section, proposed	176



YC 66340

